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WM. SPRARAGEN
Editor

AMERICAN WELDING SOCIETY

EDITORIAL AND BUSINESS OFFICES

33 West 39th St.
New York, N. Y.

ANNUAL MEETING

The Annual Meeting of the American Welding Society will be held in New York on April 22 to 24.

The Meetings and Papers Committee have arranged an unusually attractive program covering a wide range of subjects and new developments in the welding field. Almost every paper will be worth the time and cost of attendance.

The Structural Steel Welding Committee will present its report covering a two-year period of investigations. This report will include test data obtained from specimens made up at some forty leading fabricating shops. A large attendance is expected.

BOUND VOLUMES

Bound volumes of the Journal for the year 1930 are now available in attractive imitation black leather covers. This volume contains a wealth of information on all phases of welding. Price per copy $5.00. Subject and Authors' Indices permitting easy reference are included. A few bound volumes for the years 1924-to-date, are still available at $5.00 per copy.

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Nine Welding Advantages on a Specific Job

(Reprinted from December, 1930, issue, *Civil Engineering*)

TO THE EDITOR: I have read with interest the paper which F. P. McKibben wrote on the subject of "Arc Welding on Steel Buildings," contained in the October issue of *Civil Engineering*.

The construction of our 14-story office building in Boston, containing about 1300 tons of steel in the frame, has recently been completed. This building is approximately 110 ft. long by 58 ft. wide by 178 ft. high, from the sidewalk to the top of the sign platform on the elevator penthouse.

The following specific advantages were found as a result of welding the steel frame of this building:

1. Construction noise was virtually eliminated.
2. Cost of erecting and welding the steel was $3.00 less per ton than with riveted construction.
3. Accident hazard was greatly reduced by absence of falling rivets. In another local construction enterprise, where rivets were used, serious trouble was encountered.
4. Fire hazard was also reduced by the elimination of hot rivets.
5. Progress on the welded construction equaled the speed of riveting.
6. The welded building frame was more rigid than riveted construction; ordinary structural clearances allowed were not needed. Derrick work proceeded without shaking or swaying of the frame.
7. Alterations made necessary by errors or changes were more easily made than on a riveted structure.
8. Welding required simpler and less expensive stagings than riveting.
9. Smaller gussets were used for wind bracing with the welded structure.

J. L. FADEN,
Edison Electric Illuminating Company of Boston

Boston, Mass.
November 10, 1930.

Conference on Welding

The Case School of Applied Science in Cleveland announces a two-day educational conference, Feb. 19 and 20. There will be demonstrations of the latest equipment, materials and methods used in the various welding processes; problems of welding as applied to manufacturing, maintenance and construction. Special emphasis will be given to design of welded structures and machines, and to the influence of welding on the proportioning of such structures and machines. A registration fee of $2 will be charged.

Contributors to Fundamental Research Fund

In the last issue of the JOURNAL in connection with a description of the recent inspection trip and conference conducted under the auspices of the Fundamental Research Committee of the American Bureau of Welding, there was given a partial list of the contributors that made this inspection trip and conference possible. A corrected list of the contributors follows:

Air Reduction Sales Company,
American Steel and Wire Company,
Page Steel and Wire Company,
General Electric Company,
Babcock and Wilcox Company,
Lincoln Electric Company,
F. T. Llewellyn,
Metal and Thermit Corp.,
Union Carbide & Carbon Corp.

Rules for the Second Lincoln Arc Welding Prize Competition

(From News Release)

The Jury of Award

The jury of award will be composed of the members of the Electrical Engineering Department of Ohio State University and any outside advice that they shall determine. The jury will be under the chairmanship of E. E. Dreese, head of the department.

The jury shall have the sole determination of the relative merits of the competing papers submitted in accordance with the mandatory requirements. The decisions of the jury shall be final and binding.

Awards

The Lincoln Electric Company of Cleveland, Ohio, agrees to pay to the winners, after the judgment of the jury, the sum of $17,500, as follows:

For First Prize Paper	$7,500
For Second Prize Paper	3,500
For Third Prize Paper	1,500
For Fourth Prize Paper	750
For Fifth Prize Paper	500
For Sixth Prize Paper	250
For Seventh to Forty-first Prize Papers (each)	100

Judgment

Papers will be judged by the jury according to the amount of saving in first cost and upkeep resulting from the application of arc welding to the described redesign or new design.

The savings in first cost and upkeep which the papers should show, should be proportionate savings over the design previously used. In addition to proportionate savings, gross savings also should be shown and any other material bearing on the economic or social importance of the redesign.

Communications

All communications relative to the competition should be addressed to The Lincoln Electric Company, Cleveland, Ohio.

Eligibility

Any person, or group of two or more persons, in any country of the world may submit a paper in this competition. Only one paper from any competitor or group will be eligible. Employees of The Lincoln Electric Company are barred from the competition.

Relation with Subject

Each competitor must have participated in the work that forms the subject matter of his paper. The work described should be the product of a firm or company with which he is or has been connected, either as employee or in consulting capacity. In each case the relation of the competitor to the work and to the producing or developing organization must be stated.

Subject Matter

The subject matter of the paper must come under one of the following headings:

(a) A description of a useful machine, structure, or building, previously made in some other way, that has been redesigned in whole or in part, so that arc welding is applied to its manufacture.

(b) A description of a machine, structure, or building not previously made that has been designed in whole or in part to the use of arc welding and a description showing how a useful result is obtained which was impractical by means of other methods of manufacture. It is not necessary that the machine as redesigned should have been manufactured at time of writing of the paper.

Treatment

The description must be practical and of sufficient clarity to be readily understood by those skilled in the art.

Comparisons as to efficiency and cost should be made with processes previously used. Savings must be clearly substantiated. The competitor may use any method by which he believes these savings can be proved.

Limitation

The machine or structure described must have been actually designed. However, no machine or structure is eligible as a subject which has been redesigned for welding and sold in the open market, or generally used, prior to June 1, 1930. This limitation, however, does not refer to any preliminary studies, investigations or laboratory work which may have been done at any time, provided the finished product to which it relates was not sold in the open market, or generally used, prior to June 1, 1930.

SECTION ACTIVITIES

BOSTON

There was an attendance of about 225 at the January 28, meeting of the Boston Section. This was a joint meeting with the Boston Society of Civil Engineers. A buffet supper was held previous to the meeting with an attendance of 138.

The meeting was on the planning, specifying, supervising and welding of the new 14 story Edison building. The speakers of the evening were:

A. G. LEAKE, *President*,
Leake and Nelson Company,
Bridgeport, Conn.

J. T. WHITNEY, *President*,
Whitney Engineering Company.

J. L. FADEN, *Industrial Heat. Eng'r.*
The Edison Electric Illuminating Company of Boston.

Slides and motion pictures were used.

Various committees have been formed in the Boston Section to start preparations for the National Convention to be held here in September, 1931.

CLEVELAND

The January meeting of the Cleveland Section was held on the 29th. Mr. James Hodge of Babcock and Wilcox Company presented a paper on "Welding of Fired and Unfired Pressure Vessels." The talk was accompanied with a series of slides and the question of tests was covered in the paper. This meeting proved to be of unusual value and interest.

DETROIT

The regular monthly meeting of this section was held on January 26 on Structural Steel and was well attended. The "Code for Fusion Welding and Gas Cutting in Building Construction" was discussed at some length. Motion pictures and slides of actual design and erection work were shown. The meeting was carried forward as an open forum and every one from the actual welding operator to the designing engineer had valuable comments to make.

The next meeting of this section will be on March 24 with a talk by Mr. P. W. Eassler of the Fisher Body Corporation on "Resistance Welding."

LOS ANGELES

At the January meeting held on the 19th the following officers for 1931 were inaugurated:

Chairman—Paul E. Jeffers, Consulting Engineer.

Vice-Chairman—W. A. F. Millinger, M. E., Shell Oil Company.

Sec.-Treas.—Eric Barnett, Research Engineer, Columbia Steel Co.

Revision of By-Laws—C. J. Nyquist.

Membership—J. J. Bruton.

Executive Committee—C. W. Martin, L. A. McMullen, Don Llewellyn, J. O. Kilian, Turner Smith, G. J. Carroll, Frank Longo and Frank S. Brady.

After the election of officers, a motion picture showing the all welded "Upper Carnegie Building" in Cleveland, was presented by the Lincoln Electric Co. This was followed by a discussion of various methods of structural welding.

PHILADELPHIA

Messrs. Donald J. Riddell, G. Exley and C. I. McGuffie, of the General Electric Company will talk on "Recent Developments in Automatic Arc Welding" at the February 16 meeting of the Philadelphia Section.

PITTSBURGH

On January 14, the subject of the welding of structural steel was discussed by Andrew Vogel, Architectural Engineer, General Electric Company, Schenectady, N. Y., at a joint meeting held by the Pittsburgh Section of the American Welding Society and the Civil Section of the Engineers' Society of Western Pennsylvania. Over 300 engineers, architects, erectors, welding supervisors and city engineers listened to Mr. Vogel discuss design, method of erecting and inspecting two fourteen-story and one nineteen-story office building in Boston, Mass., Wilmington, Del., and Dallas, Tex., respectively.

The speaker showed about 100 slides which depicted all phases of the welding of structural steel. Mr. Vogel proved convincingly that great progress had been made in this particular field of welding and that the future prospect of further rapid growth was most promising.

Mr. Vogel was kept busy for over an hour answering pertinent questions which were indicative of the great interest held by the engineers in the vicinity of Pittsburgh in the possibilities of welding large steel buildings.

SAN FRANCISCO

The members of the San Francisco Section have been invited by Rear-Admiral G. W. Laws, Commandant of Mare Island Navy Yard, to attend the laying of the keel of an all welded auxiliary vessel on Monday afternoon, February 9. This vessel will be of all welded construction, being 118 feet in length and having a beam of 26 feet, and one of the first all welded boats to be built on this coast.

There will be no meeting during February of this Section but all members are urged to attend the sessions sponsored by the Society at the Exhibition. The following is the list of papers to be read at the sessions sponsored by the American Welding Society:

Tuesday, February 17, 2 p. m., Exposition Auditorium, American Welding Society: Miles C. Smith, Stoody Corporation, Whittier, Cal., "Recent Developments in Welded-on Overlays."

W. H. Dunlap, Aluminum Research Laboratories of Aluminum Company of American, Pittsburgh, "Welding Aluminum and Its Alloys."

Wednesday, February 18, 10 a. m., St. Francis Hotel, American Welding Society: A. F. Davis, Lincoln Electric Company, Cleveland, "Structural Arc Welding—A Review of What Has Been Accomplished and Its Future."

J. C. Hodge, Babcock and Wilcox Company, Barberton, Ohio, "A General Specification for Welded Pressure Vessels."

Services Available

A-117. Electric welder with ten years' experience on boiler work and high pressure work. Also pipe work.

A-118. Welder desires position.

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A-120. Electric welder with six years' experience on light gauge, tank and structural steel work.

A-121. Acetylene welder specializing in high pressure pipe lines.

Welding Progress in 1930

✦ This review of progress was prepared by Meetings and Papers Committee of the American Welding Society.

Structural Steel

THE arc welding of steel structures continued to fulfill the prophecy of 1928 and 1929 with the erection of a number of large office buildings and an increasingly large number of smaller structures of various kinds that were partially or entirely welded. The new headquarters of the Southern California Edison Company, started the latter part of 1929, is a thirteen-story structure approximately 150 feet in height, and with a ground floor plan of 180 feet by 180 feet. Approximately 3500 tons of steel were required, which was partly riveted and partly arc welded. Nearly 50,000 feet of weld were required. Vertical loads were carried by rivets, but all earthquake and wind bracing was welded, which required elaborate designs in some cases.

Close on the heels of this came the fourteen-story building of the Edison Electric Illuminating Company of Boston, located on fashionable Tremont Street, facing the Common. This structure occupies a ground area approximately 110 feet by 58 feet. The large ratio of height to width involved some interesting problems in wind bracing which were solved. In order to take advantage of standard shop practice, thus encouraging the maximum number of bidders and insuring the minimum cost, the steel was shop riveted. The location of the building in a district of fashionable and exclusive shops, and important office buildings, led the Edison Company to decide to eliminate as much construction noise as possible and to erect the steel by arc welding. Of the 1314 tons of steel, 1050 were framed together by welding, which was begun on April 28, 1930, and completed June 27, a total of 1205½ man hours. The total length of welds was 60,514 inches, requiring approximately 2600 gross pounds of electrode.

Simultaneously the Du Pont Company added a fourteen-story addition to their main office building at Wilmington. This was arc welded without disturbance to the occupants of offices in the original building.

But the distinction of erecting the tallest all-welded building was to go to the Dallas Power and Light Company, whose nineteen-story shop and field arc welded office building is nearing completion as this is written. Not to be outdone, the Dallas Gas Company is also arc welding in its new office building.

The Dallas Power and Light Building contains 1300 tons of steel, is 246 feet above the foundations and has a ground floor plan 100 by 100 feet. Welding was started July 23 and completed Sept. 20. Five welders at most were employed.

A fact worthy of note in connection with these jobs is the small number of welders and welding machines required. On the Boston building three welders did most of the work, with a fourth added later. On the Dallas building four machines were used.

The Westinghouse Electric and Manufacturing Company built a three-story addition to the Research Laboratory at East Pittsburgh, Pa., involving 340 tons of steel, which was all welded. At the Newark, N. J., plant of the same company the combination warehouse and service building has been completed of all-welded design, containing 1061 tons of steel. At the East Pittsburgh manufacturing plant of the same company there has been completed a large tank shop 674 feet long, the main aisle of which is 75 feet wide and a subaisle 30 feet wide, containing 450 tons of steel of all-welded construction. At the same plant a parking garage for passenger automobiles has been completed which contains 200 tons of steel of all-welded construction which are assembled and erected without the use of any field erection bolts. The largest activity at this plant is that of the Central Engineering Laboratory, which is approximately 120 feet wide, 220 feet long and 191 feet high, containing 1975 tons of steel of all-welded design.

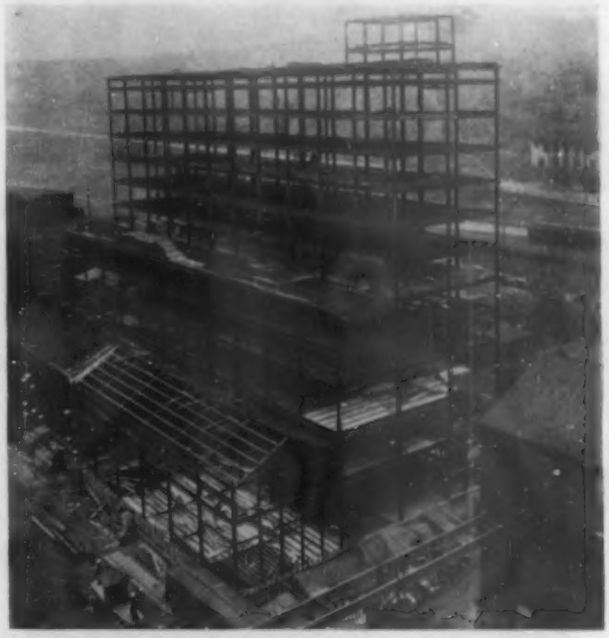


Fig. 1—Central Engineering Laboratory of the Westinghouse Electric & Manufacturing Company Under Construction

Another interesting piece of construction work is that of the Forest Lawn Memorial Park Mausoleum at Glendale, Cal., completed by the Pacific Iron and Steel Company of Los Angeles, Cal. A particular feature of interest in this building construction is the heaviest all-welded truss which has been produced to date, i. e., one weighing 60 tons having a span of 96 feet and a height of 18 feet. The weight of the entire welded building structure is 123 tons.

Applications of the arc welded battledeck type floor, developed in previous years, was extended during 1930 under the sponsorship of the A. I. S. C. An interesting example was the welding of the floor of an addition to the Berkshire Garage in Pittsfield, Mass. This floor is 40 feet by 160 feet and will not be covered nor treated in any way. A research laboratory in Milwaukee containing 150,000 sq. ft. of battledeck floor was constructed during 1930 by a slot welding process. One of the large steel companies is using this type of construction for the charging floors of two new open-hearth furnaces. One of these was welded by hand, the other with a battledeck welding machine.

A number of companies are now producing resistance welded steel joints as standardized product. Steel frames for residences are being fabricated by the resistance welding process as are, also, window and door frames.

The Ford Motor Company has erected a score of

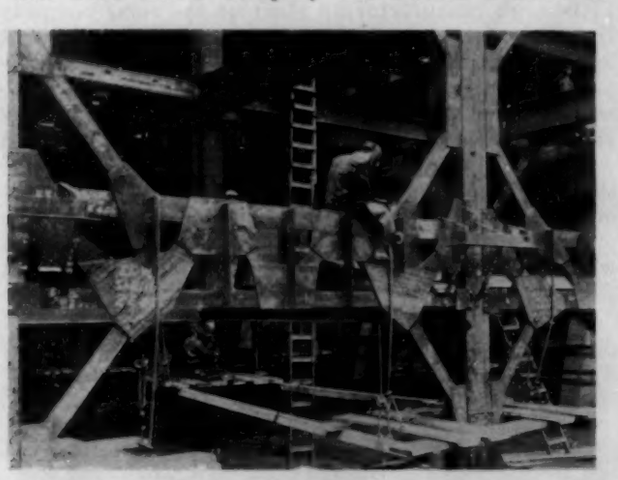


Fig. 2—Welding Wind and Earthquake Bracing for Southern California Office Building

Fig. 3—Automatic Welding of Battledeck Floor in Berkshire Garage

buildings from structural steel resistance welded together end to end, utilizing scrap channels, angles, piping, etc., from 183 emergency fleet ships.

Pipe Line Construction

Pipe line construction received a tremendous impetus during 1930 as a result of the decisions made by several large companies that economic and other factors warranted the building of large diameter, high pressure natural gas lines of unprecedented length to carry gas from the producing areas to communities a thousand or more miles away.

One factor which had an important influence in the making of these decisions was the splendid operating record of thousands of miles of welded pipe lines that had already been laid. Another was the introduction of thin-walled, high strength pipe of large diameter, which made possible a large saving in pipe tonnage on these long lines.

An outstanding development in oxy-acetylene welding during 1930 was the introduction of a new method of welding, by means of which welds of superior quality and strength can be made in from 30 to 60 per cent less time and with a lower consumption of oxygen, acetylene and welding rod. This new method has already been applied with marked success in pipe line construction and it will undoubtedly have a profound influence on the application of oxy-acetylene welding in many other fields. By the end of the year several hundred miles of pipe lines welded by this new method were in the ground.

Another outstanding development in pipe line practice was the use of specially designed liners. These liners are of thin material, and about 1¼ to 1½ in. wide. They fit the inside of the pipe joints under the butt joint. Liners permit the operator to fuse readily for the full wall thickness. The liner fits the inside of the wall so snugly that there is little, if any, obstruction to the flow of the transmitted fluid. For

Fig. 4—Oxy-Acetylene Welding 12-Inch Pipe Line

the larger diameter pipe, the use of liners has proved to be particularly economical and advantageous.

For pipe lines 20 in. or less in diameter, the generally accepted practice is to solid weld the line. For lines over 20 in. the advisability of providing for contraction and expansion has led to the development of composite construction, in which two, three or more lengths are welded together to form sections which are then joined by a coupling that will provide for expansion and contraction.

The year 1930 also witnessed the beginning of an entirely new phase of pipe line activity, the building of lines to carry gasoline. Construction was started on a number of very long gasoline lines totaling several thousand miles.

Pipe for oil, gas and water lines are now shipped in 48 ft. lengths. Resistance welding is being used to a large extent to join two sections of 20 or 24 ft. lengths of pipe before leaving the factory. Where it is necessary to dismantle pipe lines, bolted coupling are used to join the various lengths of pipe. These couplings are rolled from flat steel sections and resistance welded into cylindrical shapes. Resistance welding is used to weld flanges to standard bends and tube turns and tees, elbows, etc.

Cast Iron Pipe—A recent development is the production of cast iron pipe with the ends made slightly thicker to provide a heavier section for welding. Tests, confirmed by examination of bronze-welded lines that have been in the ground for several years, indicate that there is no accelerated corrosion at bronze-welded joints. Increasing the thickness of

the ends of the pipe will, of course, provide further assurance against the possibility of joint corrosion.

Piping

Throughout the country there is a decided trend toward the use of welded construction for piping systems for various services in buildings, industrial plants and power plants.

In a very large percentage of all new large office buildings being constructed in the principal cities welding is being employed in the construction of the

Fig. 5—Welding 8-Inch Gasoline Line in California

heating piping. In the group of buildings composing the new Cornell Center Hospital in New York, there will be a total of approximately 45 miles of oxy-acetylene welded pipe, which comprises all the piping above 2-in. size.

An interesting development during 1930 was the completion of the first installation of panel heating in this country, in the new British Embassy at Washington. All-welded construction is absolutely essential to the successful operation of this system of heating, as all heating coils are permanently embedded in the ceilings or in some cases in the side walls and floors of the building.

During the year the Committee on Welding of the Heating and Piping Contractors National Association in cooperation with leaders in the oxy-acetylene industry completed the preparation of a "Standard Manual on Pipe Welding" which includes specifications and standards covering welding of steel and wrought iron pipe. This manual will undoubtedly be of great assistance to heating and piping contractors and the specifications adopted by the Association will insure a high quality of work in this important field.

Other developments involve the use of resistance welding for the rapid production under commercial conditions of standard steel piping.

The research work done at the Bureau of Standards has demonstrated the strength and efficiency of resistance welded tubing, and the research work done in the testing of aircraft joints has demonstrated methods of assembling this tubing into important structures by fusion welding. There have also been interesting developments in the perfection of machinery for resistance welding of tubing of this sort and also pipe. Altogether, it appears that the foundation has been laid for a promising future development of welded tubular structures.

"Safe-ending" of locomotive flues and superheater tubes by the resistance welding process have become standardized products of a number of railroads.

Aircraft Industry

During the past year, the Bureau of Standards completed its investigation of the "Strength of Welded Joints in Tubular Members for Aircraft" and this was published as Report No. 348 of the National Advisory Committee on Aeronautics. This fundamental research was undertaken to provide the aircraft industry with information on the strength, weight and cost of a variety of typical welded aircraft joints. The data obtained will be of great value to the designer as well as to the production department.

The almost universal use of oxy-acetylene welding for the fabrication of fuselages and other parts from mild steel and chrome-molybdenum tubing is being supplemented by the welding of other alloy steel

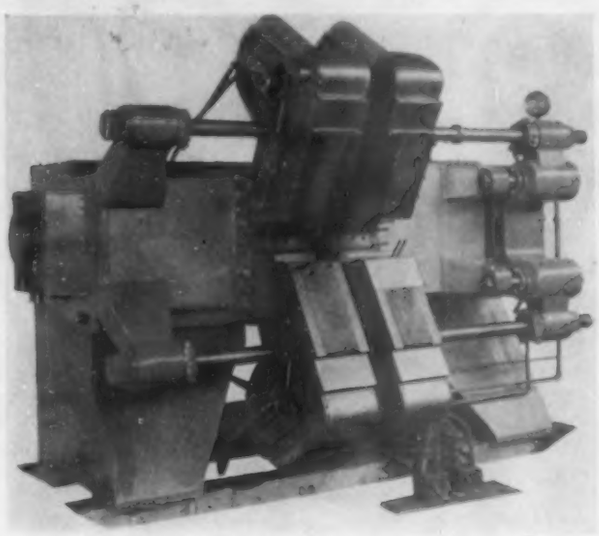


Fig. 6—A Resistance Welding Machine for Welding Pipe up to 6 Inches in Diameter

structures such as wing beams, tail surfaces and landing gear which are heat-treated after welding. Other recent developments include the welding of strong aluminum alloys and an increasing use of welded chrome-nickel steels for parts where corrosion resistance is important, such as exhaust stacks and collector rings.

Pressure Vessels

Probably the most interesting development in this field is the issuance by the A.S.M.E. of Code Revisions for Pressure Vessels which are proposed for adoption in the A.S.M.E. Code for the Construction of Unfired Pressure Vessels. The following allowable or "working" stresses are given in this revision: For longitudinal seams, double V-butt welded, 8000 lb. per sq. in.; for girth or head seams, single V-butt welded, 6500 lb. per sq. in.; for girth seams, double full fillet lap weld, 7000 lb. per sq. in.; for girth or head seams, spot or intermittent welded, 5600 lb. per sq. in. The above stresses are approved if the pressure vessel is fabri-

cated by welding in accordance with the recommended procedure for fusion welding of pressure vessels given in the Appendix.

Highway Construction

Steel mats for thousands of miles of highways are resistance welded in factories and shipped to the place of use.

Machinery Construction

Manufacturers of equipment have made a greater proportion of their machinery of welded construction during the past year than ever before. One phase of

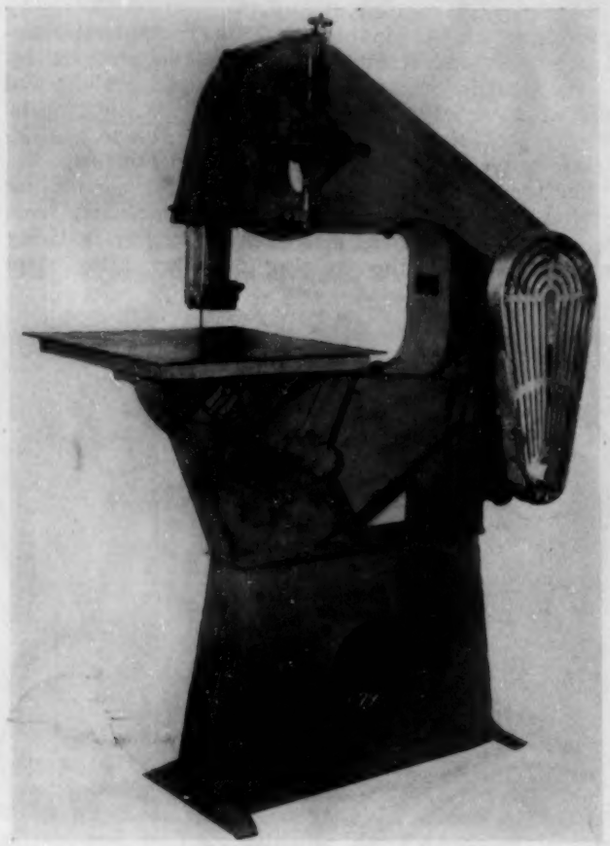


Fig. 7—Arc-Welded Frame for Band Saw

this construction which has been received with particular interest from the welding standpoint is that of constructing jigs, fixtures and special shop machine tools by the welding process where it has proven to be of great economic advantage not only from a first cost standpoint but from the standpoint of being able to tool up much more quickly than where cast structures are used.

Construction equipment, including tractors, concrete mixers, excavating shovels, line cars, cranes and derricks are making increased use of welded construction and gas cutting.

During the year the use of automatic shape-cutting machines for the production of special shapes in steel plate, slabs, forgings, etc., rapidly increased. Shape-cut steel parts are now supplied to order by several large steel distributing organizations, and a number of shops specialize in the production of shape-cut steel as well as of finished products made from shape-cut parts.

Motor frames for small and large size motors are rolled from mill section plates and resistance welded into cylinders. Wheels and rims of farming machinery, such as, tractors, traction engines, harvesters, trucks, etc., are all resistance welded.

Ship Construction

The Truss-Weld Barge Corporation launched an 8000-barrel capacity gasoline tanker of all-welded construction which is 134 feet long.

The Electric Boat Company at Groton, Conn., has completed a 1000-ton cargo deck barge 118 ft. long, 37 ft. wide by 10½ ft. deep of the all-welded Ewertz patented design. In the construction of this barge 150 tons of steel was used and approximately 18,000 linear ft. of welding was performed requiring about 3500 lb. of welding wire.

The Federal Shipbuilding and Drydock Company, at Kearny, N. J., constructed a number of barges by means of arc welding.

This company used oxy-acetylene welded construction for cargo pumping piping systems and high pressure steam piping from boilers to turbines in two large oil

Fig. 8—Shape Cutting with Oxy-Acetylene Shape-Cutting Machine

tankers being built for the Standard Oil Company of New Jersey.

The Fore River Yard of the Bethlehem Shipbuilding Corporation delivered two colliers 350 ft. long each with transverse seams of their tank tops welded and with bulkheads wherein two rows of rivets were replaced by one row of rivets and a continuous weld.

The Charleston Dry Dock and Machine Company completed a 120-ft. oil tanker and at the Standard Steel Shipbuilding Corporation, Los Angeles, Cal., a 65-ft. yacht was completed by the arc welding process. Two merchant ships, the "Morro Castle" and "Oriente," were constructed at the plant of the Newport News Shipbuilding and Drydock Company for the Atlantic Gulf and West Indies Navigation Company. The outstanding new applications on these ships are completely welded inboard shaft alley bulkheads, masts and bilge keels.

Oxyacetylene heating torches have been developed for shipyards to facilitate heating plates and angles for shaping and bending during the process of erection. These torches, consuming 200 cu. ft. acetylene and upwards per hour, furnish convenient means of rapid local heating wherever required. Their use avoids much transportation of material to and from the ship and the making of expensive templates because the shaping, bending and fitting can be accomplished in direct relation to the mating parts.

Railroad Welding

More and more applications have been made of welding to details of cars, and some major welding operations have been made tending toward the development

of all-welded cars. Progress in this direction is somewhat hampered by government regulations.

Maintenance of way welding to repair worn rail ends has become general practice on many roads. The savings in labor and material and the improvement of riding quality resulting, make this work of great economic importance. Many railroads repair low joints immediately, thus saving further deterioration of track and wear and tear on the rolling stock.

Along with the building up of rail ends, which has

Fig. 9—Building Up Worn Rail Ends

effected important savings, also, is the repair of switch points, frogs and crossings. This practice is becoming more and more general. Welding done on track which lengthens the useful life of the steel, puts further in the future the date when the rails must be removed and replaced, involving heavy capital expenditure for rails and labor.

Aluminum Alloys

During the year there was a marked increase in the welding of aluminum alloys, particularly the strong alloys designated 17S, 25S and 51S. Among the more important welded products fabricated from the strong aluminum alloys are: Motor truck bodies, gasoline truck tanks, window sash, window screen frames and roof structures. One of the most recent developments is the welding of extruded aluminum in the production of bank fixtures, modernistic furniture, lamps and other ornamental work.

Welding of Brass

Procedures have been developed for oxy-acetylene welding of brass pipe which will enable the architect and the piping contractor to obtain the advantages of welded construction with brass pipe.

Investigations have indicated that welding rods of approximately 60-40 composition will give uniformly good results with the commercial brass alloys used for pipe. On pipe containing over 60 per cent copper, the operation is essentially bronze-welding because the melting point of the pipe metal is above that of the welding rod. This is an advantage as it permits making the weld without actually melting the base metal. This avoids the tendency of brass, except that made especially for welding rod, to be unsound after remelting. Either the plain butt joint or the bell and spigot type joint is suitable for bronze-welding. The latter has considerable advantage in making welds on pipe which is in a vertical position.

Automotive

There has been a tremendous increase in the use of all the welding processes in the automotive industry during the year in order to reduce production cost.

The use of resistance welding requirement in in-

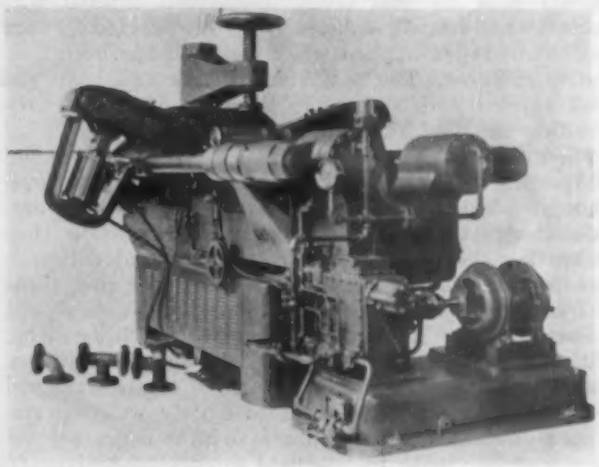


Fig. 10—Machine for Resistance Welding 12-Inch High-Pressure Elbows and Tees

dustry at large and especially in the automotive field, has gone forward rapidly.

Welding Rods

Noteworthy advances have been made in the development of special welding rods and coated and covered electrodes to insure greater speed and greater strength of welds. Welds with ductility comparable to parent metal are now possible.

Equipment

Automatic Machines—The use of automatic arc welding of several different forms has increased rapidly during the past year, and industry as a whole is becoming cognizant of the advantages of machine produced welds where the nature of the work is such that the necessary tooling is economically warranted.

An improved portable semi-automatic arc welding equipment suitable for use with either the open or hydrogen shielded arc, was perfected. The welding tool is arranged so that it may be readily changed from one to the other.

Atomic Hydrogen Welding—The atomic hydrogen welding process, developed some years ago, was further extended in usefulness by its adaption to automatic welding.

This permits greater speeds with higher currents than were feasible with the hand operation of this process.

Arc Welding Machinery—Several new types of machines have been designed to give the welding circuit of single-operator machines greater stability than has been previously developed for arc welding circuits. This has eliminated the usual initial surge of current which is experienced when the electrode is touched to the work by an operator which obviates the tendency

for the electrode to freeze to the work. "The time of recovery" has been reduced to a small fraction of a second.

Rivet Cutting Tips—Rivet cutting tips of new design have greatly accelerated the removal of rivets and stay bolts from boilers. The speed at which this work can be done means substantial reduction in cost. Operation of the new type tips requires less experience and manual skill to avoid injury to the boiler sheets. In the case of cutting button head rivets, the oxyacetylene jets are directed against the head substantially in line with the axis of the rivet, and the head dissolves completely into oxide in 8 to 10 seconds. The operation takes place so quickly that the cold sheet underneath covered with oxide is not heated sufficiently to be affected by any excess of oxygen applied when the head has been completely removed. The new rivet cutting tips have also been applied with success to the dismantling of cars, speeding up rivet removal and reducing cost.

Machine Cutting Torches—The chief development in the machine cutting field has been the improvement of a multiple torch cutting machine which provides control of all torches from a single station, thus permitting the operator to give undivided attention to the operation of the machine while cutting two, three or four shapes simultaneously.

Portable Gas Welding Equipment—An illustration of the extreme adaptability of the oxy-acetylene process is found in answering the demand of air transport companies for light, portable, complete welding stations to be carried by airplane so that necessary repairs can be made in the field on disabled aircraft. An ingenious outfit weighing considerably less than 100 lb. and permitting several hours' welding has been produced and is being used in both Americas along the routes of the great air transport lines.

Resistance Welding Machinery—In the last year, projection welders have been built that require over 3000 KVA power to operate them. Some of the projection welders will make as many at 24 projections at one time and require 60,000 lbs. of pressure to mash down the 24 projections. In other words, the work is done in 1/24 of the time that it formerly took to spot weld these one spot at a time.

Thermit Welding

Welding Rail for Open Track—The developments started in 1929 on the Thermit welding of rail for open track construction and on the methods of welding street car rails without interrupting traffic have progressed very rapidly. A number of installations of this combination pressure and fusion weld have been made and, even in heavy service, the wear of the joint appears to be no greater or less than that in other portions of the rail. The head portions are pressure welded, thus eliminating all cast material from the running surface.

Thermit Insert Joint—Many improvements have been made in the Thermit insert joint which have tended to better the average results obtained regardless of the efficiency of the preheating before welding and of the quality of the mold material used by the various properties. The Thermit weld continues to be standard in the majority of the street railway properties of the country.

Rail Welding Under Traffic—This method has developed rapidly because of the numerous instances where traffic cannot be removed from the rails and where extensive rehabilitation is not undertaken. The present design allows the car wheel to pass over the joint without the use of a jumper or bridge during the entire welding operation except for the few minutes required for the pouring of the joint and the removal of the cope or upper part of the mold. Many thousands of joints have been put in this way and the application is very practical.

Reclamation in Steel Mills—Each year shows an enormous increase in the welding-reclamation work and, during 1930, probably the most popular branch of this has been the building up of worn surfaces by the instantaneous addition to this surface of a metal much more wear resistant than the original metal. In fact, designs of new parts sometimes include allowance for the deposition on surfaces exposed to wear of this hard Wabbler Thermit steel.

Pipe Welding—Thermit pipe welding resulting in a pure pressure weld between the pipe ends continues to find considerable application, but is yet, as formerly, limited practically to diameters of 6 inches and less. An improvement has been made in this work which has resulted in the elimination of the slight bulging or distortion occasionally noticed at the bottom of such pipe welds and in a much more uniform micro structure in the weld area of the entire periphery.

Apparatus Improvements—In addition to the development of the clamps and apparatus required particularly for pressure welding of rails and that required in the welding of rails under traffic an improved light portable preheater has been developed which has many advantages of rigidity, compactness and low center of gravity while retaining all of the excellent qualities of the former apparatus. Certain features of design have also made considerable improvement in the efficiency of operation and consequently the time of preheating.

Tests of Welds

Within the past year great advances have been made in methods for the non-destructive testing of welds. These come, in general, under three heads:

1. X-ray.
2. Stethoscope.
3. Electromagnetic.

In order to meet a demand for some means that would facilitate the testing of welds under field or average shop conditions, there has been introduced a portable tensile testing machine by means of which welders' qualification test specimens can be examined immediately.

Discussion of American Welding Society's Structural Welding Code

By **H. H. MOSS**

✦ This paper was read before the 31st Annual Convention, International Acetylene Association, Chicago, Ill., Nov. 1930. Mr. Moss is Engineer of the Linde Air Products Co., New York.

STANDARDIZATION of practices in manufacture and construction, which designers and workers in these fields of industry employ, is the milestone which marks the transition from what may be termed individualistic production to that of mass pro-

duction. This applies, generally speaking, to the specializing fields of manufacture or construction as well as to those fields which have been more or less generally invaded.

It is an American axiom, particularly in the basic industries, that mass consumption is the reward of standardization. By this means, uniformity in quality and resultant usefulness is assured and by the same process the maximum economy is obtained.

As each new art, economically useful in the industrial scheme of things, is brought to the point where its production practices have reached the stage where they may be properly standardized, so may we log the progress in the development of that art to the point of common usefulness.

In the welding field, which has, in a little more than a decade, invaded practically every known field of industrial activity, we are constantly confronted with the work of standardizing proven applications so that mass utilization can proceed. In detail it amounts to passing the design standards and welding technique on to regulating bodies, executives, engineers and the welding craft generally.

One of these which has recently received the joint consideration of the welding industry is the art of welding as applied to the fabrication of steel frames for buildings.

It was not long after the early stages of development in this field dating back about six years, which bore good evidence to those who witnessed the results that fusion welding was a practical tool for the joining of steel building parts, that demands were made upon the welding industry for specifications or rules whereby others might employ this tool.

Specifications setting forth the rudiments of the art prevailing in different schools of thought at that time were submitted in answer to these requests. Upon these data quite a few structures were erected by welding.

Along with this action, further development work was going on at the hands of special interests sponsoring structural welding until nearly 10,000 tons of structural steel had been so erected.

In going back to review the practices of that time, one will find considerable disagreement as to the detail prescription on design and welding technique compared with the practices commonly recognized at this time.

Unit working stresses for fillet welds varied from 7500 to 11,000 lb. per square inch. For butt welds, from almost entire prohibition to 13,000 lb. per square inch. The design criteria for joint preparation and for the position of joints or welds encountered in structural assemblies were quite vague. Applied design was as varied as was design of reinforced concrete during its early stages of development. The recommended welding technique varied considerably and the language of welding was inconsistent, making it difficult for the layman to understand different commentators.

Nevertheless the art progressed and the singular feature of it all was that no failures occurred. The structure stood up under the loads imposed. True, the costs were not always favorable compared with the costs of the methods of construction which were replaced, but there was good indication that due economies would be realized in time.

In the second stage of the development of structural welding which marked the appearance of welded building structures inside the jurisdictional provinces of municipal building laws, the first real obstacle to its further progress on a broad commercial scale was encountered. The laws in the cities wherein these structures were permitted to be built (the permits being obtained through special permissions granted by Departments of Buildings upon evidence of unusual ability on the part of those understanding the work) did not provide for this modern tool of construction.

The regulatory personnel of the Building Departments had little, if any, knowledge of welding and it was only natural that strong resistance was placed against the employment of this method of construction at the hands of the construction industry practicing within these cities.

Concurrent with these developments, a considerable amount of dispute was going on in connection with the merits of gas cutting in the shaping of steel parts for buildings. A measure of the protests causing these disputes was, no doubt, justified as it was observed that the practices of gas cutting in this field were not in all cases in agreement with the practices for this tool as recommended by our industry. There was an evident lack of proper understanding of the purpose of this tool.

The confidence, essential to any method of construction if it is to enjoy wide usage, was lacking and uniformity in these several applications was not in sight.

In answer to this situation the American Welding Society took a definite step to bring the responsible interests together in order that there could be effected a meeting of minds as to the factors in structural welding and gas cutting essential to sound design and application. The Society appointed a Committee on Building Codes whose first work was to render whatever assistance it could logically give in matters of inquiry or dispute in connection with these applications and to draft regulations for fusion welding and gas cutting in structural steel for buildings upon the practices which had reached a stage where they could be properly standardized.

Upon investigation the committee found considerable material upon which to build and it promptly started to fulfill these assignments and by the close of 1928 had completed a draft of a Structural Welding Code, which the Society published early in 1929. This code was entitled "Code 1, Part A, Code for Fusion Welding and Gas Cutting in Building Construction, Edition of 1928."

Copies were distributed throughout the United States and Canada, one copy being submitted to all Building Departments on record at that time in this country. Five thousand copies of this edition were printed, but within a few months after it was made available the first edition was exhausted. A second edition was obvious, but while considering this step it was recognized that the reference matter, consisting of two publications of the American Bureau of Welding, would have to be likewise reprinted. In short, the committee decided to republish the code so that reference to the Bureau publications would not be necessary in order to obtain a complete interpretation. The edition of 1930 resulted, which was made available in October of this year, and which is now being distributed throughout the United States and Canada.

The 1930 edition, quoting from its preface, includes an appendix which is primarily a digest of the publications referred to in the 1928 edition, with the explanatory matter where needed to make it more applicable to code purposes. A few minor changes were made in the body of the code, which are explained in the 1930 preface.

The code, therefore, in its present form, not only

provides proper specifications for applied structural welding and gas cutting, as agreed upon by the welding industry at large, but also contains sufficient practical data on arc and gas welding to enable construction executives to differentiate between acceptable and non-acceptable workmanship.

The results of this work of standardization are beginning to be felt. To date nearly 100 cities and towns have adopted, either in whole or in part, the recommendations given in the body of Code 1, Part A, among which are the cities of Sacramento, South San Francisco, Berkeley and Pasadena, Cal.; Shreveport and Monroe, La.; Helena, Mont.; Olympia, Wash.; Albuquerque, N. M.; Utica and Syracuse, N. Y.; Lynn, Mass.; Wilmington, Del.; Dallas, Tex., and New Orleans, La. This means that structural welding by arc and gas methods and gas cutting of structural steel along the lines recommended in the code are permitted to be used in these towns and cities under the regular procedures of construction.

Many cities now working on revision of their building codes are considering a similar action, among which are some of our largest municipalities.

The code is being recognized as a standard by organizations which are promoting better construction and it has been observed that current applied design is in good agreement with the recommendations set forth in Code 1, Part A.

The process of standardization is in operation. Structural welding practices are being leveled out throughout this country and the characteristics of development in this field at the present time are more along the lines of economic design that in details concerned with unit stress, weld technique, and the like.

The accrued welded tonnage in buildings and bridges at this time, should all data be assembled, would approximate 100,000 tons, involving structures of the simple one-story type to the twenty-story building. In bridge work, structural welding will be encountered in both highway and railway structures, and the number of jobs in contemplation at this time offer a very promising outlook.

The following is the personnel of the Committee on Building Codes as constituted at this time:

F. T. Llewellyn, Chairman, U. S. Steel Corp.
J. L. Anderson, Air Reduction Sales Co.
H. G. Balcom, Consulting Engineer.
C. T. Bissell, National Board of Fire Underwriters.
Frank Burton, Steel Joist Institute.
E. A. Doyle, The Linde Air Products Co.
Gilbert D. Fish, Westinghouse Electric & Mfg. Co.
Grover A. Hughes, Truscon Steel Co.
J. C. Lincoln, Lincoln Electric Co.
F. P. McKibben, General Electric Co.
H. H. Moss, The Linde Air Products Co.
James W. Owens, Welding Engineering & Research Corp.
Edmund Von Steeg, General Electric Co.
C. C. Whittier, R. W. Hunt Co.
Herbert A. Woofter, Swift Electric Welder Co.

A Fourteen-story Office Building Field Arc-welded in Boston, Mass.

By **FRANK P. McKIBBEN**

✦ This paper was presented before the Pittsburgh Section of the American Welding Society by Prof. F. P. McKibben, who is consulting engineer for the General Electric Company.

WHEN one sees the two-thousand-year-old Roman bath tub exhibited in the Field Museum in Chicago, made of pieces of bronze welded (brazed) together, with handles attached to the body of the tub by bronze rivets, he recalls the old and familiar quotation from Ecclesiastes 1:9, that "There is no new thing under the sun." But when he stands on historic Boston Common to view the Edison Electric Illuminating Company's fourteen-story office building being arc-welded on Tremont Street, opposite the Common, he is inclined to think that the old adage is wrong, or possibly that welding a structure so large is merely an "exception that proves the rule."

The arc-welding process is developing so rapidly that no sooner do we decide that a fourteen-story welded structure is "the latest thing," when the beginning of an all-welded nineteen-story office building in Dallas requires us to establish a new standard. Seemingly the end is not yet.

The Edison Building is nearly rectangular in plan; 58 ft. on Tremont Street, 110 ft. at right angles thereto, and 187 ft. high from the sidewalk grade to the top of the sign platform on the elevator pent house. Because the structure is surrounded by hotels and office

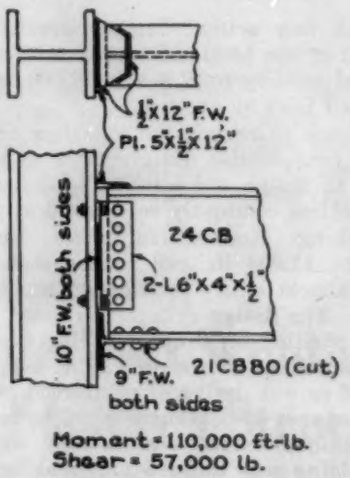


Fig. 1—Typical Connection of 24-in. Girder to Column Flange; Moment 110,000 Ft-Lb. Shear 57,000 Lb.

Note: In. Figs. 1, 2, 3, 4, 6, 7, and 8 all rivets and bolts are of ⅞-in. dia.; and the welds are ⅜-in. fillet welds unless otherwise noted

buildings, field welding was decided upon to reduce the noises of construction, but as this is the first building in Boston to be welded and in order to secure as many bidders on the steel as possible, standard riveted shop connections were used. This made it possible for the Edison Company to receive the benefit of competition by permitting existing steel fabricating com-

panies to utilize their customary shop practices, while at the same time securing the advantages of reduction in noise by adopting arc-welding for field connections.

The steel frame is therefore shop riveted and field welded.

Design

Because of the relatively narrow width of 58 ft. as compared with the height of 187 ft., provisions to resist rather high wind stresses were necessary in proportioning the steel members and their connections. Figs. 1, 2, 3 and 4 illustrate four types of wind connection for varying amounts of wind moments.

Fig. 1, depicting a typical connection of a 24-in. girder beam to the flange of a column where a moment of 110,000 ft-lb. is to be transmitted, shows a "wind connection" consisting of a girder beam cut to form a T which is shop riveted to the lower flange of the 24-in. beam and its flange field welded to the face of the column. At the top flange of the 24-in. beam, the stress is transferred from the beam to the column by

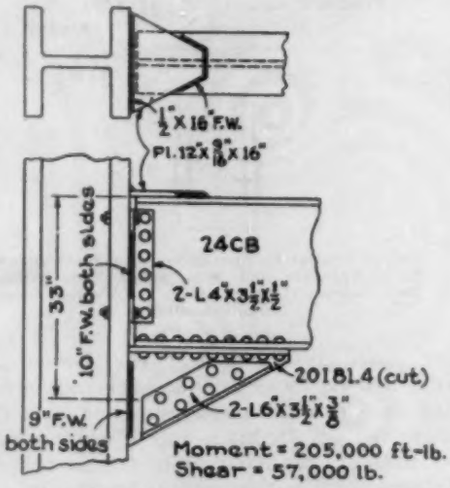


Fig. 2—Typical Connection of 24-In. Girder to Column Flange; Moment 205,000 Ft-Lb. Shear 57,000 Lb.

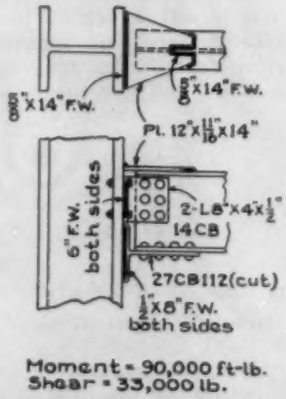


Fig. 3—Typical Connection of 14-In. Beam to Column Flange; Moment 90,000 Ft-Lb. Shear 33,000 Lb.

a 5-in. by ½-in. by 12-in. plate field welded both to beam and column. The end shear of 57,000 lb. is carried into the end connecting angles by six shop rivets, thence into the column by 20 in. of ⅜-in. field welding. The customary way of designating field welding by the letters *FW* is indicated in Fig. 1.

In those cases where the end bending moment on the girder is larger than can be provided for by the design in Fig. 1, the split girder beam is arranged as in Fig. 2. It acts as a gusset to increase the effective depth; the flange of the split beam being shop riveted to the lower flange of the girder, and the left edge of the web field welded with 18 in. of fillet to the face of the column. The connection in Fig. 2 is one in which the sloping edge of the gusset is stiffened by two 6-in. by 3½-in. by ⅜-in. angles.

Another interesting connection of a 24-in. girder

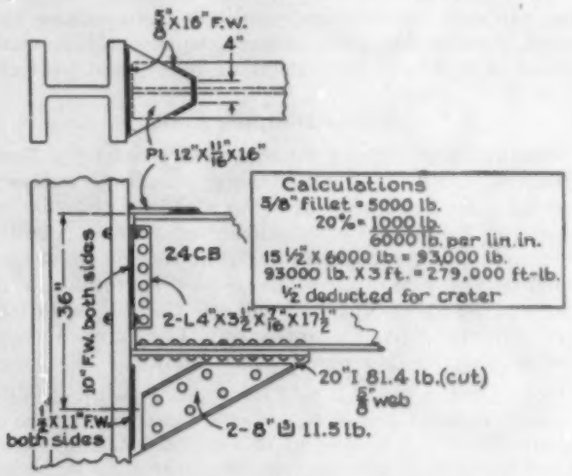


Fig. 4—Typical Connection of 24-In. Girder to Column Flange; Moment 279,000 Ft-Lb. See also Fig. 10

to the flange of a column is shown in Fig. 4, where the web of the split 20-in. I-beam is reinforced by two 8-in. channels. Consider the moment carried by the welds at top of the 24-in. girder and those near the bottom of the bracket. At the top are 16 in. of ⅝-in. fillet, which for the live and dead stresses are good for 5000 lb. per linear inch of fillet at 11,300 lb. per sq. in. of minimum section. But for combined wind, live, and dead load, 20 per cent additional is used, making 6000 lb. per linear inch. From the 16 in. of fillet, ½ in. is deducted for crater, leaving 15½ in. effective welding. This at 6000 lb. provides a strength of 93,000 lb. Multiplying this by the lever arm of 3 ft., the available moment is 279,000 ft-lb., without allowing anything for the erection bolts or the 20 in. of fillet on the end connecting angles.

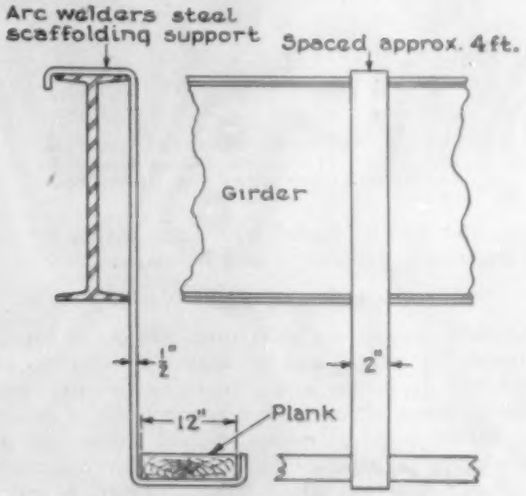


Fig. 5—Steel Yoke for Supporting Plank to Serve as Welder's Platform

With wind-gusset plates used in this kind of welded connection, it is important to have the vertical edge of the split girder web in line with the back of the connecting angles in order to secure a proper joint for field welding.

Sufficient field bolts were provided to insure proper plumbing and bracing in erection, and to draw the steel closely together preparatory to welding. The steel frame, both before and after welding, was unusually rigid.

The specifications for welding included the following subjects: definitions, quality of materials, apparatus, permissible unit stresses, workmanship, qualification of welders, proportion of parts, and protection of steel.

Boston Building Code

The building code of Boston, prescribed by a Massachusetts statute of rather long standing, makes no provision for welding; but being a code of the "flexible" type, the Building Commissioner granted a permit to field weld the structure under that section of the code which gives him discretionary powers to use a new material upon receipt of evidence that it is satisfactory for the purposes intended. The particular section embodying this power is as follows:

"Systems Not Covered by This Act.—If an applicant for a permit to build desires to use as a substitute for the materials or methods covered by this act materials or methods of construction or maintenance not covered by it, he shall present to the commissioner plans, formulæ, and such other information, and shall make such tests or present satisfactory evidence of such tests, as the commissioner may require. Such systems shall not be used until after the commissioner has issued general regulations fixing the methods to be followed, but no such regulation shall have the effect of altering the working stresses for any material herein mentioned or of reducing the fire-proofing requirements of this act."

The New England Building Officials Conference is now engaged in preparing a uniform building code, and no doubt provisions for welding will be incorporated therein. At all events, if this organization is successful in formulating such a desideratum as is a uniform code, and it is adopted by cities throughout New England, a great forward step will have been

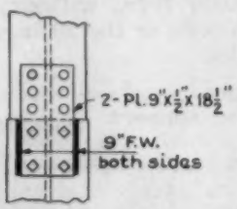


Fig. 6—Typical Column Splice with Both Splice Plates Narrower Than the Column Flanges for Use Where No Interference with Welding Exists

taken, and will be hailed with satisfaction by numerous engineers, architects, and builders.

Erection and Field Welding

All field connections at column splices, at connection of beams to beams, and of beams to girders, and at connection of beams and girders to columns are arc-welded. Many cities permit connections of secondary floor beams to be permanently field bolted, but as the normal Boston practice is to rivet these connections, they were field welded in this structure, a few bolts being used in each place only for erection purposes.

In general it was not necessary to erect platforms or other supports for the welders while at work on the various joints, but in those cases where platforms were needed they consisted of a short plank supported in steel yokes made by hooking a light Z-shaped steel frame over the top flange and alongside of the floor beam, Fig. 5. The cost of staging required for welders is small in general, and certainly in this Boston building the cost was very slight.

Four welding machines were used, each a single-operator motor-generator set; all were set on the first floor where they remained throughout the work except during a brief period when moved to permit the reinforced concrete floor slab to be cast at their original location. In general it is preferable not to set the welding machines in the building, because they may interfere with building operations as in this case where they had to be moved during concreting. There was

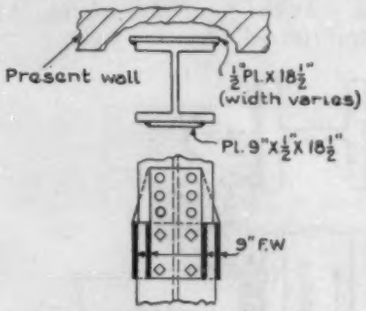


Fig. 7—Typical Column Splice with Front Splice Plate Narrower and Rear Splice Plate Wider Than Column Flange to Allow for Welding From One Side Only

no other space available near the Edison Building, however. A meter was provided for each machine for recording the electrical energy supplied. As the building is not over 187 ft. high, only a slight drop in voltage was noticed, resulting from the increased length of leads necessary as the welders worked on the upper stories. In general it may be said that the amperage was approximately 175 at the lower and 185 at the upper floors. Three welders were employed until May 13, when a fourth was added. These four welders, one welding foreman and one "engineer" constituted the entire welding force. For four welding machines, only four welders and one welding foreman are needed.

Fig. 8—Typical Connections for Beams to Beams

Typical column splices are shown in Figs. 6 and 7, the former indicating the usual design for the splice where the column is in such a position that all sides are accessible for welding, while Fig. 7 illustrates a case where welding can be performed from one side only because of the column being located against the wall of an adjacent building. By the simple device of using a narrow splice plate on the front and a wider one on the rear flange, the welding was done from the front without interference from the wall, and no cutting into the wall was necessary so far as welding was concerned.

Typical connections of beams to beams are shown in Fig. 8. Thus, for the 15-in. and 18-in. I-beams, two 4-in. by 3½-in. by ½-in. angles with a total of 16 linear inches of ⅜-in. fillet are used to carry the end shear. As the permissible unit stress is 3000 lb. per linear inch for live and dead loads, this end welding is capable of carrying 3000 times 16 or 48,000 lb. in

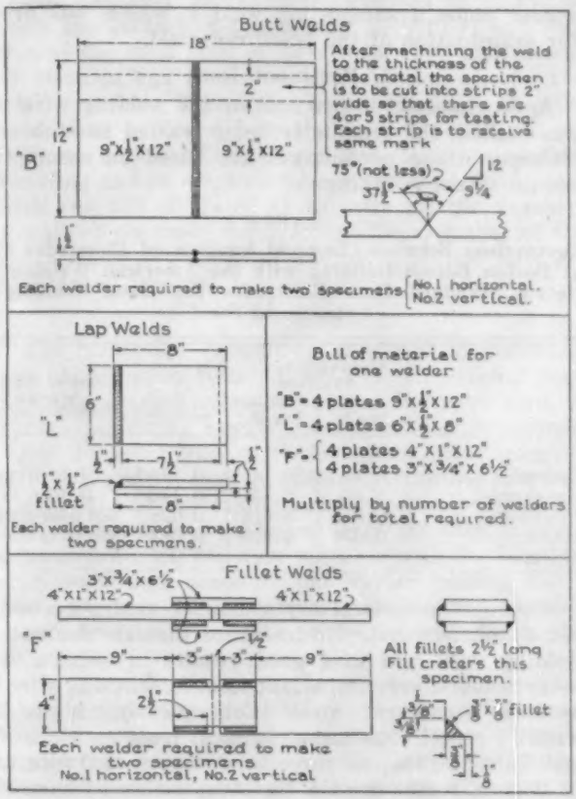


Fig. 9—Specimens for Qualifying Welders

direct shear. The connecting angles provide flexibility.

Qualification of Welders

The work was begun with three welders and a fourth was added later. The ability of each of the four men was established by qualification tests. Of other men who took the tests, some failed and others met the requirements, but none of these were employed on the building, as the four welders were found to be sufficient.

These qualifying tests to determine the welders' competency consisted of three types, Fig. 9: butt welds designated *B*, lap welds designated *L*, and fillet welds *F*. These three types are presented as follows in the order in which the specimens were prepared:

Lap Welds "L": Each welder was required to make two specimens, each consisting of two 6-in. by ½-in. by 8-in. plates with their 6-in. edges offset ½ in. These plates were clamped together and welded by hand along the 6-in. dimension. Upon cooling, the plates were broken by wedging at the free ends, and the broken weld examined for proper fusion with both plates; for density and texture of weld metal; for good penetration into the right-angle corner of the fillet; for freedom from gas holes, slag inclusions, and other defects.

It is scarcely necessary to add that when such plates are broken apart a good weld will break through the throat or minimum section, leaving a portion of the weld metal adhering to each plate throughout the entire 6-in. distance.

This test is so simple that it was given first and if the welder could not meet these requirements he was not permitted to proceed with the other tests.

Butt Welds "B": Two specimens, each consisting of two 9-in. by ½-in. by 1-ft. 0-in. plates, were butt welded with a double Vee joint, one welded horizontally, the other vertically. After the weld reinforcement was removed by grinding or machining until the weld was reduced to the thickness of the plate, four or five test strips each 2 in. wide were cut from each specimen and tested in tension. The average tensile strength of each group of the two sample plates was not to be less than 45,000 lb. per sq. in.; and the tensile strength of the lowest in each group not less than 40,000 lb. per sq. in.

Fillet Welds "F": Each welder was required to make at least two samples as shown by *F*, Fig. 9, one specimen welded horizontally, the other vertically. On each side of the splice are a total of 10 in. of ⅜-in. fillet. In fairness to all parties concerned the welding inspector insisted that the fillets be ⅜ in. and each of 2½ in. length as shown. The 2½-in. dimension was made small to accommodate the testing facilities of the ordinary laboratory, but as a variation in length of a small amount may constitute a considerable percentage, the length of the fillet was as near 2½ in. as was possible to secure. Moreover, although in general it is best on the building to leave the craters normal (*i.e.*, not filled) in making these fillet specimens *F*, for sake of standardization each crater was filled to the full section of the ⅜-in. fillet, and the 2½-in. dimension included the filled crater. These specimens were tested in a tension machine, thus subjecting the welds to longitudinal shear, the ultimate value of which was a measure of the welder's ability. The two specimens were to average a total pull of at least 117,000 lb. corresponding to 44,000 lb. per sq. in., or

Fig. 10—Connection of 24-In. Girder to Column Flange, Showing Field Welding of Wind Bracing Bracket and End Connecting Angles to Column. (See also Fig. 4)

11,700 lb. per linear inch shearing value on the minimum or throat section of the weld; and the lowest value of the two was to be not less than 101,100 lb. total pull, corresponding to 38,000 lb. per sq. in., or 10,110 lb. per linear inch of fillet. The lowest figure, 38,000, was so small that the welders whose minimum value did not at least reach that amount were rejected.

The highest ultimate tensile strength of the butt welds made by the seven welders who qualified was 56,500 lb. per sq. in. and the lowest was 43,700 lb. per sq. in. The average was 52,790 lb. per sq. in. This figure compares very favorably with 54,125 lb. per

sq. in. which was the average value of tensile strength of four such specimens welded by the inspector, who had had much experience in welding.

Tests of the fillet-welded specimens made by the seven welders showed that the maximum load was 155,200 lb., equivalent to an average longitudinal shearing strength of 15,520 lb. per linear inch of fillet and corresponding to a shearing strength of 15,520 lb. divided by 0.266 sq. in., or 58,350 lb. per sq. in. of minimum (throat) section of the fillet. The minimum breaking load was 105,600 lb., equivalent to an average longitudinal shearing strength of 10,560 lb. per linear inch of fillet or 39,700 lb. per sq. in. on the throat section.

Butt-welded specimens with the weld reinforcement removed should give practically the same results whether welded in the horizontal or in the vertical position, and this was the case in this instance wherein the tensile strengths of the horizontally-welded and the vertically-welded specimens were 53,208 and 52,371 lb. per sq. in. respectively.

With fillet-welded specimens, however, one should expect to find a slightly greater average shearing strength for specimens made with the fillets welded vertically, because of the natural tendency for the molten metal in this position to form fillets which, instead of being triangular in cross section, have sections approaching a quarter of a circle. This was the case with the fillet-welded specimens of the qualification tests, the average shearing strength of all the specimens welded in the vertical position being 13,780 lb. per linear inch as compared with an average of 13,000 lb. per linear inch for all those welded in the horizontal position. The effect of this change in shape of the fillet's cross-section may be very marked. For example, the throat distance of a ⅜-in. quarter-circle fillet is 0.375 in. as compared with 0.266 in. for a ⅜-in triangular fillet, an increase of 0.109 in. or 41 per cent of 0.266 in. One does not expect in ordinary welding to secure such marked differences as this, but it is possible to do so by enlarging the throat. (In depositing vertical fillets the welding should proceed upward.)

Before adopting the qualification test specimens *F* shown in Fig. 9, one should be sure that the testing machine available has sufficient size of opening in the grips to hold the specimens, sufficient clearance between the heads of the machine to accommodate the length at fracture, and sufficient capacity to break pieces of the size shown.

For this Boston building, at least twice a week each welder made a sample lap weld *L* which was broken for examination of the fractured weld.

Pertinent Data

Approximately 80 per cent of the welding wire used was melted, the remainder being wasted as stub ends. However, these percentages are based on assumption, not on actual weighing.

TABLE I

Comparison Between Chemical Analyses of Electrodes Used at Boston Edison Building with the American Welding Society's Standard Bare Electrodes for Hand Welding of Structural Steel

	Manufacturer's Analyses		Our Analysis	American Welding Society's Grade E—No. 1B
	5/32 In.	3/16 In.		
	%	%	%	%
Carbon	0.14	0.14	0.133	0.13–0.18
Manganese	0.40	0.45	0.440	0.40–0.60
Phosphorus	0.016	0.018	0.028	Not over 0.04%
Sulphur	0.034	0.029	0.024	Not over 0.04%
Silicon			0.007	Not over 0.06%

Although a satisfactory chemical analysis alone is not a sufficient criterion to insure that an electrode or welding wire will give good results in service, it is nevertheless a very important item in selecting wire for welding structural steel. Consequently, it is the writer's practice to make chemical tests on electrodes, and Table I presents three analyses on the wire used in Boston, together with the composition of bare electrodes specified by the American Bureau of Welding for arc-welding structural steel by hand.

It would be a rare coincidence were two steel build-

TABLE II

PERTINENT DATA REGARDING FIELD WELDING OF BOSTON EDISON BUILDING

Electrode (total of used and wasted) 5/32-in., 1500 lb.; 1/4-in., 1100 lb.; total	2,600 lb.	Electrical energy required to melt one pound of electrode, 6120/2080	2.94 kw-hr.
Electrode melted (assumed 80% of total)	2,080 lb.	Welding man-hours per ton of steel in building, 1205.5/1314	0.917 hr.
Electrical energy used	6,120 kw-hr.	Welding man-hours per ton of steel welded, 1205.5/1050	1.148 hr.
Total structural steel	1,314 tons	Electrode melted per ton of steel in building, 2080/1314	1.582 lb.
Structural steel welded	1,050 tons	Electrode melted per ton of steel welded, 2080/1050	1.98 lb.
Actual welders' time (man-hours)	1,205½ hr.	Electrode melted and wasted per ton of steel in building, 2600/1314	1.98 lb.
Total length of 5/16-in. fillet	51,921 linear in.	Electrode melted and wasted per ton of steel welded, 2600/1050	2.48 lb.
Total length of 1/2-in. fillet	7,188 linear in.	Electrode melted and wasted per hour per welder, 2600/1205.5	2.16 lb.
Total length of 5/8-in. fillet	1,405 linear in.	Electrode melted and wasted per linear inch of fillet, 2600/60,514	0.043 lb.
Total length of all fillets	60,514 linear in.	Electrode melted per linear inch of fillet, 2080/60,514	0.0343 lb.
Fillet per ton of steel in building, 60,514/1314	46.05 in.	Electrical energy required per ton of steel in building, 6120/1314	4.66 kw-hr.
Fillet per ton of steel welded, 60,514/1050	57.63 in.	Electrical energy required per ton of steel welded, 6120/1050	5.83 kw-hr.
Fillet deposited per welding man-hour, 60,514/1205.5	50.2 in.		
Fillet deposited per man per 8-hour day	33 ft. 6 in.		
Fillet deposited per pound of wire used and wasted, 60,514/2600	23.27 in.		
Fillet deposited per pound of wire melted, 60,514/2080	29.09 in.		
Fillet deposited per kw-hr., 60,514/6120	9.9 in.		
Electrode melted per kw-hr., 2080/6120	0.34 lb.		

ing frames exactly alike. Certainly the details of construction vary greatly; and consequently Table II giving pertinent data for this building should be applied with extreme care in other cases. In studying this table, it should be remembered that the provisions for wind resistance are an important element in the amount of welding; that all secondary as well as primary beams are field welded here, whereas in many other cases the secondary beams may be bolted; and finally, that of the total steel of 1314 tons, 1050 tons consisted of columns and beams welded together in the frame itself, whereas 264 tons were foundation cantilever beams and grillages devoid of welding.

For a building frame similar to that of the Edison Building and of a known tonnage of steel, it is possible with the aid of Table II to estimate the number of pounds of electrode required, the linear inches of fillets, the amount of electrical energy, and the number of man-hours required for welding.

Inspection

The inspection of welding consisted of assisting in the qualification tests of welders, in making certain that the proper electrodes and current were used, verifying the sizes, lengths, and locations of completed welds in accordance with the plans, examining each weld for quality, testing welders during the progress of the work, and in making daily reports covering in detail the number of inches of fillet for each connection deposited during the day, together with the location of each weld and name of the welder making it. The inspector was an experienced welder and previously was instructor of welding at the General Electric Company's River Works, Lynn (Mass.).

The question is frequently asked: "What do you do when a poor weld is found?" It should be cut out either by hand or by a pneumatic tool and the joint should then be rewelded. In the Edison Building this was not necessary except in one case where an error occurred in setting a column base at an incorrect elevation, which caused a few beams to be welded at incorrect heights. When this mistake was discovered the welds were cut out, the column base set correctly and the beams rewelded.

Whidden-Beekman Engineering Company, 100 Arlington Street, Boston, were designing and supervising engineers in charge of the structural steel, floor system, and foundations. The writer and his associates, Carson and Carson, 22 South Fifteenth Street, Philadelphia, were consulting engineers on welding design and execution and inspection thereof. The welding was done by the Leake & Nelson Co. of Bridgeport, Conn.

Hard-Facing in Industrial Fields*

By W. A. WISSLER *and* A. V. HARRIS

* This paper was presented before the December meeting of the New York Section, A.W.S. Mr. Wissler is connected with the Union Carbide and Carbon Res. Labs., and Mr. Harris is connected with the Haynes Stellite Company.

IN endeavoring to create interest in a new process or to lead to the adoption of a well-known but hitherto unused process, one of the first steps necessary is to give a reasonably complete idea of what advantages either in economy or uninterrupted operation may result from its adoption. The importance of hard-facing in industrial fields may thus be emphasized best by first calling attention to a large number of proven applications of hard-facing materials.

Airplane Tail Skids

One of the more spectacular uses of hard-facing is for airplane tail skids. Few persons not familiar with the details of aviation realize how short is the life of the ordinary tail skid. The length of service will vary

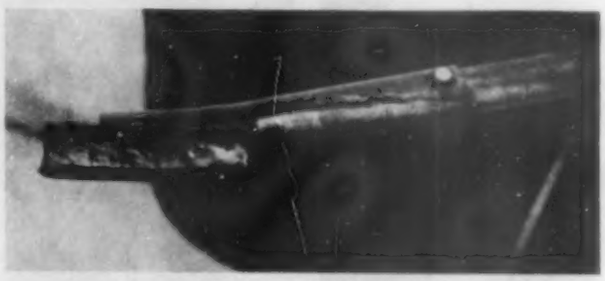


Fig. 1—Tail Skid, Hard-Set and Hard-Surfaced

greatly, depending upon the field on which it is used. Some fields are paved with decomposed granite, others with oiled cinders, and still others with just plain dirt. Detailed reports from one of the western fields, this particular field having a granite facing, showed that the average life of an ordinary skid was approximately 40 landings. Skids faced with a hard-facing alloy having an iron base lasted for 160 landings. Similar skids surfaced with Haynes Stellite were good for 400 landings. A skid, Fig. 1, made up with insets of tungsten carbide and faced with this Stellite, lasted approximately 800 landings. Thus it was possible to increase the life twenty times by the use of hard-facing metals, at an increase in cost of only about 2½ times. When the saving in labor and time of making nineteen replacements is considered, the economy of hard-surfacing is clearly evident.

Cement Mills

Hard-facing has been so successful in the cement industry that several applications have become standard practice, the most outstanding example being the hard-facing of grinder rings. The mills usually used for grinding cement consist of a ring about six feet in diameter with a ten inch face, lying horizontally, inside of which three crushing rolls revolve and rotate, crushing the cement on the inner surface of the ring.

Steel rings last about 400 hours, whereas hard-faced rings will last from 4000 to 7000 hours if kept in proper condition. The data below show the ring cost and output over a period of time equal to the life of the hard-faced ring, 7500 hours.

	Steel Ring	*Stellited Ring*
Life	400 hours	7,500 hours
Cost per ring	$135	$850
Number needed	18.75	1
Repairs		$200
Total ring cost	$2,540	$1,050
Time shut down for replacement and repairs	427 hours	30 hours
Average bbls. per hr.	125	147
Cost of rings per bbl.	.022c.	.0095c.
Increase in output		17%

Tractor Treads

Another application which, although developed in the Mid-West, can be utilized wherever ice is encountered, is the hard-facing of tractor treads. The set of treads

shown in Fig. 3 was used on a tractor pushing a snow plow over county highways in Michigan. Formerly, on this type of work a set of treads lasted but one winter, while at the end of a similar period of service, the hard-faced treads were rolled up and saved for use during another winter. Furthermore, the four raised points on each tread prevented side slippage on the ice and hard-packed snow. As the cost of a new tread is more than seventeen times the hard-facing cost, it is easy to understand why it has become practically a

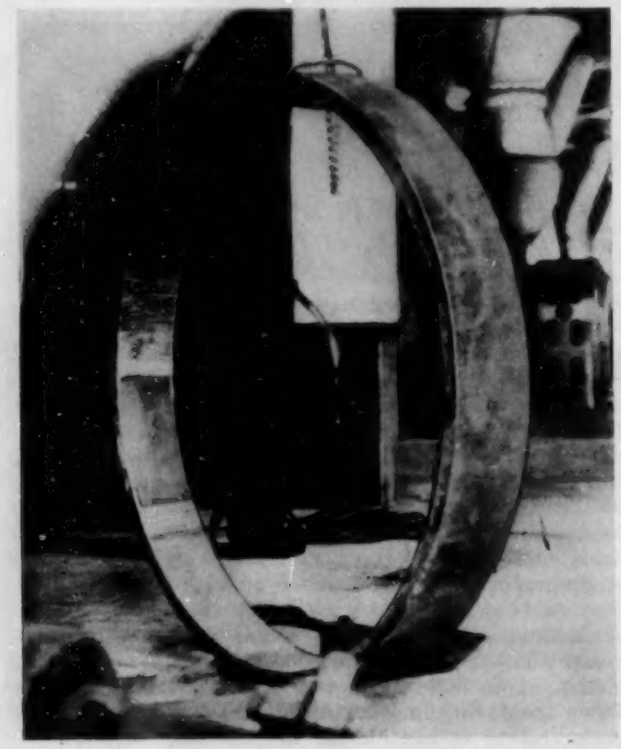


Fig. 2—Grinder Ring Partially Hard-Faced

standard practice to treat tractor treads in this manner in this locality.

Dipper Teeth

The bucket shown in Fig. 4 is one of the largest of its kind ever built. The straw hat perched between the teeth will give some idea of its huge size. It will bite out 12½ cu. yd. at a clip, an amount which will more than fill six ordinary dump carts. Each of the six teeth weighs 900 lb. These teeth, after hard-facing, removed 400,000 cu. yd. of dirt and limestone and were still in good enough condition to be hard-surfaced again. The service life of these treated teeth was seven times that of the original chrome molybdenum steel.

Coke Pusher Shoes

A coke pusher shoe, when hard-faced on the bottom, Fig. 5, far outlasts the ordinary carbon steel shoe. At the end of three months, the layer of hard-surfacing material showed a wear of but 1/32 in., while an ordinary steel shoe at the end of four months had worn down 3½ in. The wear ratio in this instance is approximately 100 to 1. An interesting point brought out by this application, is the fact that the furnace floor does not show as much wear when the shoe is hard-surfaced as when an ordinary carbon steel shoe is used. It is sometimes believed that by increasing the life of one part, the life of the part with which it is in contact is decreased. However, the opposite is usually true. This is partly because the hard-surfacing material has a lower coefficient of friction and so slides more easily over the furnace bottom. Furthermore, because of the hard, smooth surface, small particles of coke are not picked up on the bottom and plowed along with a lapping effect on the oven floor.

Dies

Hot forming and trimming dies, when hard-surfaced at their point of wear, last much longer than do ordinary steel dies. Fig. 6 shows a hard-surfaced die for forming Ford brake pedals, with which thirteen times as many pieces were turned out before it was necessary to replace the die. Furthermore, after the hard-faced surfaces have worn down, it is possible to rebuild the worn part and put the die back into service.

These few axamples show conclusively the economy resulting from hard-facing parts that are subjected to abrasion. However, there is a wide choice possible in the type of material to be used for hard-surfacing. These may briefly be divided into four classes. The first of these comprises alloys that are relatively low in price such as white iron or manganese steel; the second consists of alloys having an iron base and containing appreciable amounts of carbon and such elements as chromium, tungsten, manganese, silicon and sometimes cobalt and nickel. The third class is composed of the non-ferrous alloys, represented at the present time almost exclusively by Haynes Stellite, which is an alloy of tungsten, chromium and cobalt. The fourth class consists of the so-called diamond substitutes which are essentially tungsten carbide, nearly all of them being in the cast condition.

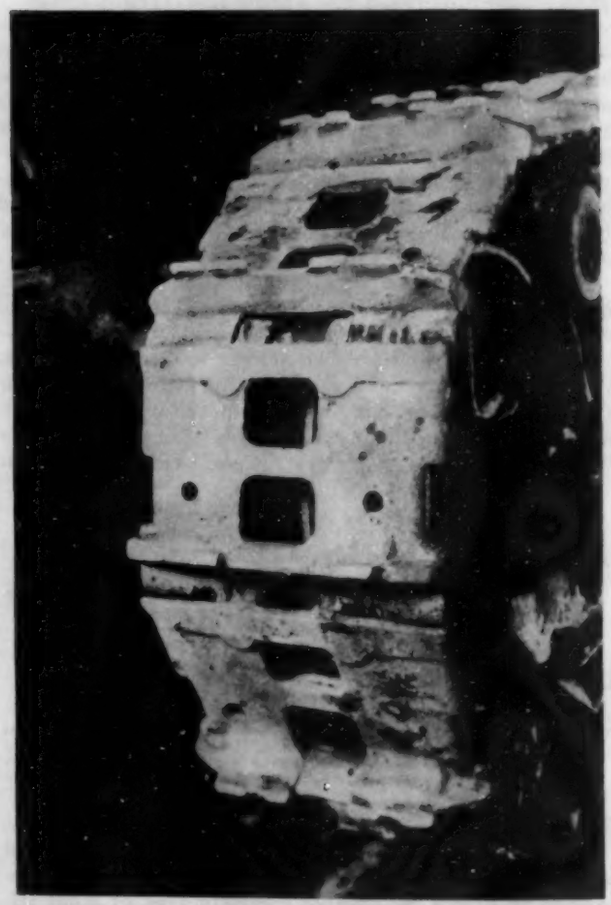


Fig. 3—Tractor Treads Coated to Combat Abrasion

The first of these classes which consists of very cheap material should be used only in cases where the wear is very slight. The second class of materials may be used under conditions of moderate abrasive wear. This class begins with alloys that are soft and are actually high alloy steels, and covers a range of increasing hardness in which alloys containing only 55 per cent of iron are being used. Softer alloys may be used to resist moderate abrasion, and have also been used as a

Fig. 4—Huge Bucket with All Teeth Hard-Faced

filling material for the harder alloys. It must be understood that they are considerably lower in price, and if a badly worn part is to be reclaimed, it is often economical to rebuild the piece with a cheaper rod and use the high grade rod on the surface only. In the third class, the non-ferrous alloy rods are designed in proportions to give good welding properties and maximum wear resistance. The fourth class of diamond substitutes have an extremely high melting point and cannot be melted with the oxy-acetylene flame. They are accordingly used as pieces of various sizes that are embedded in a hard-facing material which is welded to their surfaces and holds them in place so that their superior wear resisting properties can be utilized. It is only fair to add that the field of use for these inserts is more limited than that for the alloys of other types, all of which are completely melted during their application.

There are several physical properties that must be carefully considered in the selection of a hard-facing material. One of these is its coefficient of expansion; and it is unnecessary here to go into this point at any length. Strength is another quality, for it must be remembered that these metals have low strength as compared to steel. Probably the most important property is hardness, although a thorough knowledge of the nature of abrasive wear must be possessed in order to be able to discuss these alloys from a hardness point of view.

Everyone will realize that mechanical friction always develops heat. This heat is liberated at the contact surface between the metal part and the other material, whether it be metal, rock, wood, dirt, or anything with which it comes in contact when it moves. These temperatures exist only while the motion is continuous, and then only in a very thin surface film, perhaps considerably less than one-thousandth of an inch in thickness. However, it must be remembered that this surface film contains a very large number of layers of atoms of the alloy, and if the alloy is one that becomes soft at these temperatures, the surface will be worn away. Hence, hardness is of great value to a hard-facing metal, but it is red hardness and not cold hardness that determines the wearing life of a surface coating in many cases.

Of all the alloys of the first three classes, or to be more inclusive, all of the alloys that can be melted with a welding blowpipe when applied as a coating, the non-ferrous cobalt-chromium-tungsten alloys have the highest degree of red hardness. At ordinary temperatures they may be slightly softer than the alloys having an iron base, but as the samples are heated, it is found that the iron base alloys soften fairly rapidly. At temperatures of 400 deg. C. and over, the cobalt-chromium-tungsten alloys are considerably harder than the ferrous hard-facing metals. By actual comparison on a Monotron testing machine, it was found that the average hardness readings of the cobalt-tungsten-chromium alloys are 75 per cent higher than the corresponding figures for the ferrous alloys over the entire range of red heat. This retention of hardness at high temperatures exists only in alloys using cobalt instead of iron as a base material.

Regarding the methods of application, hard-facing may be done by any of the standard fusion welding methods. If the oxy-acetylene process is used, there are a few simple points to be borne in mind which distinguish hard-facing from ordinary welding. In welding it is generally considered advisable to interalloy the base metal and the welding rod to secure a good bond. In hard-facing, on the other hand, such

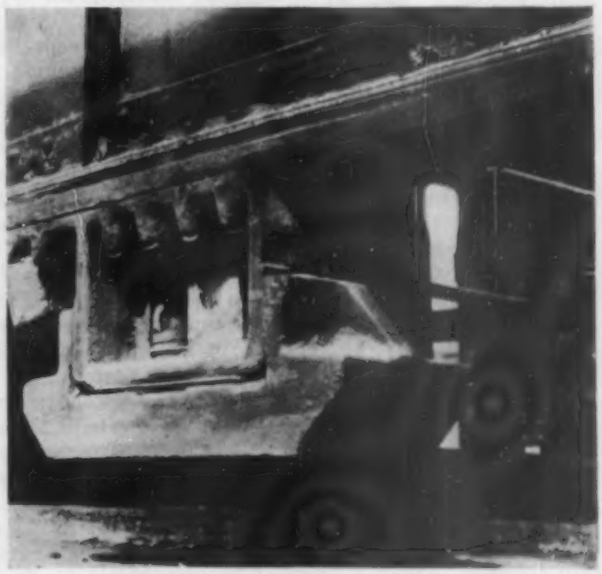


Fig. 5—Coke Pusher Shoe with Hard-Surfaced Bottom

interalloying will dilute the hard-facing metal and reduce its effectiveness to a considerable degree. Hence the aim in hard-facing is to flow the alloy material over the surface of the base metal when the latter is at a sweating heat. If this is properly done, a strong junction is secured without any noticeable degree of interalloying of the two metals. Another point to be remembered is that a flame containing an excess of acetylene must be used. The reason for this is somewhat

difficult to explain, but if this is not done, it is very hard to secure the proper sweating of the base metal, which usually results in the presence of more or less pinholes in the deposited metal. Finally, it is necessary to see that no particles of scale are covered during the process. If these precautions are taken, any welder can, with a little practice, produce a good hard-facing job.

If the arc is used, the polarity should be reversed as is common practice with most chromium-bearing alloys. It is of course impossible to avoid considerable inter-alloying of the two metals, although this should be kept at a minimum. The currents required are reasonably heavy because most of the rods are cast and have fairly large cross-sections. As a general rule, in the case of Haynes Stellite, using direct current, the ¼ in. rod requires 200 amp., and the 5/16 in. rod, 250 amp. Aside from these brief statements there is but little that could be told in a discussion of this kind on the technique of hard-facing. Each of the two processes has its own

Fig. 6—Treated Die

definite field of use and is adapted for different types of jobs.

For practically all of the smaller jobs, and especially for such applications as trimimng dies which must be free from cracks and imperfections, the oxy-acetylene method is far the better. The principal advantage in the use of this process lies in the fact that the heat can be more carefully controlled, the metal can be applied with a more even surface, and fairly sharp edges or corners can be worked up. In many cases this is a distinct advantage because it reduces the amount of grinding necessary and also reduces the amount of hard-surfacing material required. On the other hand, if the job is quite large and a rippled surface is satisfactory, and particularly if the presence of a number of cracks is not detrimental, the arc is probably preferable. It must be remembered that the use of the arc for welding results in a considerable loss of metal. Perhaps 10 per cent of the material used is lost by spattering and volatilization. In the case of hard-facing materials which are sold on a basis of several dollars per pound, a loss of 10 per cent is an item that should be borne in mind if the costs of the two processes are being considered.

The hard-surfacing applications that have been mentioned give some ideas as to the economy that may be obtained through this procedure. In practically any industry in which parts are subjected to great abrasion, the application of one of the four classes of wear-resisting materials would probably prove highly advantageous. By a careful study of the conditions encountered and an investigation of the properties of the various hard-surfacing metals on the market, thousands of dollars which are lost annually through undue wearing of parts can be saved.

Oxy-Acetylene Welded Piping for Speedy Installations

By J. P. WATERS

✦ Mr. Waters is connected with The Linde Air Products Company.

THE part that oxy-acetylene welded piping played in relieving a water famine in a northwestern city best illustrates the ease and speed with which welded piping can be installed.

To relieve the famine, it was necessary to pump water from a nearby river. This required the installation of an emergency pumping station and the construction of an elaborate piping system.

While the pumps were being delivered, the welders rushed the work on the piping which was to connect them to the 28-in. supply line through an 8-in. blow-off valve. A 12 x 12 x 12-in. tee was first fabricated by the welders, with a 12-in. heavy-duty flanged valve on each of the two outlets. The other outlet was reduced to 8 in. and was flanged to fit the 8-in. blow-off on the 28-in. line. The 6-in. connection also was welded into the side of the tee to accommodate fire department pumps which supplied the water until the large pumps were installed.

The next step was to provide the 12-in. intake, the inter-connection between the two pumps and the dis-

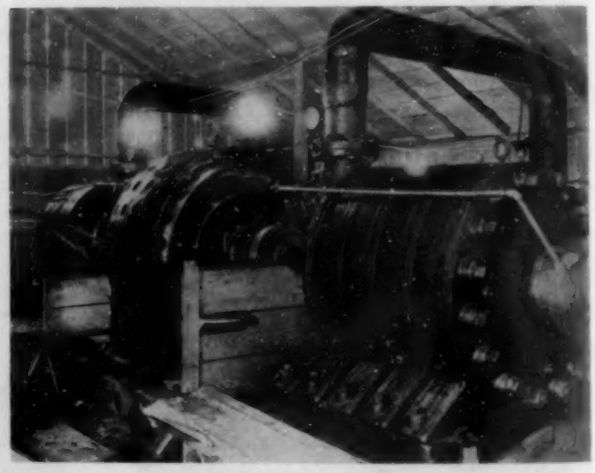


Fig. 1—Oxy-Acetylene Welded Piping in Emergency Pump House

charge line leading to the valve on the 12 x 12 x 12-in. key. This system, with its many elbows and angles, was laid out as accurately as possible before the pumps arrived and the elbows and bends were welded in advance, leaving a minimum amount of welding to be done later.

When the pumps arrived the entire system was consolidated. So accurately had the various sections been fabricated that the pumps were in operation 12 hrs. after their arrival. Although this installation required approximately 100 cuts and 50 joints in 12-in. pipe, oxy-acetylene welding made possible its completion in only 60 hrs.

Report Joint Pressure Vessel Committee Investigation of Light Gauge Welded Pressure Tanks

The Joint Pressure Vessel Committee is a committee officially created by the American Society of Mechanical Engineers and the American Bureau of Welding to conduct such investigational work as may be deemed desirable to supply needed information in the welded pressure vessel field and to conduct research when called upon by the Boiler Code Committee.

Introduction

At the request of the Boiler Code Committee of the American Society of Mechanical Engineers, the Joint Pressure Vessel Committee of the American Bureau of Welding and the American Society of Mechanical Engineers, undertook a series of tests on light gauge welded pressure tanks, the longitudinal seams of which were made by resistance welding process in which the seams were butt welded progressively for the entire portion of its length. Certain features of head construction were also tested.

The tests were made in the Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa., under the supervision of members of the Executive Committee of the Joint Pressure Vessel Committee.

Scope of Tests

The scope of the tests and the tests results are indicated in the report made by Lehigh University which follows.

In addition to these tests, bend tests have been made at the request of the committee and many specimens which were bent flat in directions parallel and perpendicular to the weld did not indicate any sign of fracture. Macroscopic and microscopic examinations were called for by the committee and a supplementary report prepared by Prof. W. E. Harvey. Results of breathing tests of tanks made by the manufacturer, but not under the supervision of the committee, are also attached.

Recommendations

Based on the results of these tests the Joint Pressure Vessel Committee makes certain recommendations to the Boiler Code Committee. These recommendations are also attached.

In particular, it should be noted that the committee has not recommended any definite fibre stress, although the tests indicate that the weld is as strong as the plate.

Recommendations to Boiler Code Committee Relative to Light Gauge Welded Pressure Tanks

Based on the results of these tests the Joint Pressure Vessel Committee makes the following recommendations to the Boiler Code Committee.

I. That provision may be made in the unfired pressure vessel code for the use of this method of fabrication which the committee defines as a resistance butt weld made progressively and with continuity over its entire length. There is some slight offset of the edges to be joined, amounting to about one-half the thickness of the plate.

II. That this method of welding be, for the present, limited to plates not thicker than 0.13 in.

III. Specification for steel plate for the manufacture of tanks by progressive welding shall be that indicated in the report by Professors Slater and Fuller, which follows.

IV. The following rules of procedure may be required:
Longitudinal seams shall have the edges of the plate and electrical contact area cleaned by any suitable method so as to render these surfaces free from any scale, oxides or grease.
The welding shall be done by bringing the two edges of the sheet together at one point and applying a current locally and continuously and while the heated section is in a plastic condition compressing the edges together in such a way as to obtain a sound weld; this heating and compressing continuing progressively throughout the entire length of shell.

V. The rules of the Boiler Code Committee for attaching heads and nozzles be revised to permit the type of construction shown in Fig. B, p. 4, of the test report on Light Gauge Welded Pressure Tanks by Professors Slater and Fuller. The use of these constructions should at present be limited to vessels in which the thickness of the cylindrical shell does not exceed 0.13.

Respectfully submitted,

Executive Committee, Joint Pressure Vessel Committee

E. H. Ewertz, Chairman;
W. Spraragen, Secretary;

C. A. Adams,
E. R. Fish,
H. M. Hobart,
D. S. Jacobus,
J. Partington,
H. L. Whittemore.

Tests of Light-Gage Welded Pressure Tanks

By W. A. Slater† and M. O. Fuller†

1. *Introduction*—The tests herein reported were made at the request of the Joint Research Committee on the Welding of Pressure Vessels to determine the strength and behavior of tanks made from light-gage metal by a resistance welding process. This committee is made up of representatives from the American Bureau of Welding and the American Society of Mechanical Engineers. The tests were made in Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa.

2. *Scope of Tests*—The tanks were furnished by the John Wood Manufacturing Company in Conshohocken, Pa. Seven tanks were furnished. Six were tested to failure under hydrostatic pressure and one was used for cutting out test coupons of the metal. The tanks were 4 ft. long and 12 in. in inside diameter. The shells were made of No. 11-gage (nominally 0.125 in.) metal and the heads of No. 9-gage (nominally 0.156 in.) metal. Of the six tanks tested under hydrostatic pressure, the three numbered 1, 3, and 5 had convex heads at both ends. Each of the other three tanks numbered 2, 4, and 6, and tank No. 7, used for obtaining test coupons, had a convex head at one end and a concave head at the other end. Both heads are of the same form and radius of curvature. The difference in manufacture consists merely in placing one head so that it is convex outward, and the other so that it is concave outward. The radius of curvature, determined from measurements of mid-ordinates on both ends of tank No. 7, averaged 11.3 in. in the portion 3 in. or more away from the center, and about 22.5 in. at the center. The convex and concave heads are shown in Fig. 1.

There were two openings in each tank, each threaded and of such size as to take a 1-in. outlet or inlet pipe. One hole was at the end in the center of the convex head, and the other was in the shell 6 in. from the end.

3. *Definitions*—The method of welding has been termed by the manufacturers the "electric resistance compression butt weld" and is described in the following extract from a letter from the John Wood Company to the Joint Research Committee on the Welding of Pressure Vessels.

"We have called our method of welding the Electric Resistance Compression Butt Weld where the current is continuous and the welding progressive, for the lack of a more suitable name, as we want to differentiate from other methods of Electric Resistance Welding.

"The word 'progressive' being used so that our method will not be confused with the Electric Resistance Butt Weld, where the entire area is welded simultaneously.

"The word 'continuous' being used so that our method will not be confused with the continuous spot weld where the current is interrupted and the welds overlap. This latter method being called the 'Continuous Spot Weld' or sometimes referred to as the 'Stitch Weld.'

"The word 'butt' being used so that our method will not be confused with

†Fritz Engineering Laboratory, Sept. 15, 1930.

that method where the current is continuous, the welding progressive, but the sheets overlapped."

Wherever in this report the term longitudinal weld is used, the weld lengthwise of the tank is referred to. The term transverse weld refers to the weld which joins the head to the cylindrical portion of the tank.

4. *Rules and Specifications*—Rules for electric resistance compression welding and specifications for the plates for this type of welding are given herewith. These rules and specifications were furnished by the John Wood Company.

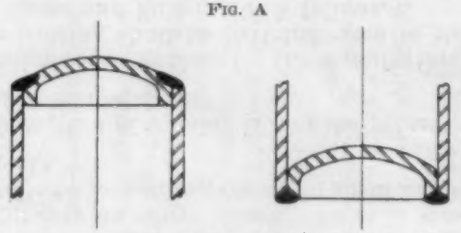
Rules for Electric Resistance Compression Welding Where the Current Is Continuous and the Welding Progressive

1. The plate used shall be made by the open hearth process and shall have the properties as outlined under specifications for steel plate for Electric Resistance Compression Welding.
2. The minimum thickness of any plate shall be ⅛ in. and this thickness allowed on shells up to and including 16 in. in dameter.
3. For threaded openings any method as shown in Fig. A may be used.
4. When properly welded by the above method of Electric Resistance Compression Welding the strength of the joint may be calculated on a maximum unit working stress of S-9600 lb. per square inch.

PRESSED STEEL

UP TO 125 #/□" WORKING PRESSURE

Fig. A



HEAD CONSTRUCTION

LARGE PORTION OUTSIDE, WELD OUTSIDE

LARGE PORTION INSIDE, WELD OUTSIDE

THREADED OPENINGS

Fig. B

†Fritz Engineering Laboratory, Sept. 15, 1930.

5. Longitudinal seams shall have the edges of the plate and electrical contact area cleaned by any suitable method so as to render these surfaces free from any scale, oxides or grease.
6. The welding shall be done by bringing the two edges of the sheet together at one point and applying a continuous current locally and while the heated section is in a plastic condition compressing the edges together. This heating and compressing continuing progressively throughout the entire length of shell.
7. Heads shall be driven or forced into the shells with a tight driving fit, as shown in Fig. B and thoroughly welded.

SPECIFICATIONS FOR STEEL PLATE FOR ELECTRIC RESISTANCE COMPRESSION WELDING

1. The steel for the shell shall conform to the following requirements as to chemical composition.

Carbon	.08 to .15 per cent
Manganese	.45 to .50 per cent
Phosphorus	Not over .04 per cent
Sulphur	Not over .03 per cent

After rolling the sheets shall be annealed, the annealing to be such as will not result in its breaking or creasing when rolled into cylindrical form and must retain sufficient rigidity and spring so as not to cause a deformity in passing through the Electric Welding operation.

2. Head sheets shall conform to the following specifications.

Carbon	.10 per cent or under
Manganese	.45 to .50 per cent
Phosphorus	.05 or under
Sulphur	.03 or under

3. *Ladle Analysis.*—(a) The manufacturer shall make an analysis of each melt of steel, from a test ingot taken during the pouring of the melts, to determine the percentage of carbon, manganese, phosphorus and sulphur. The results of analysis shall conform to requirements, and shall be reported to the purchaser or his representative.

Check Analysis.—(b) The purchaser may make an analysis from finished material representing each melt. The chemical composition thus determined shall conform to the requirements.

4. *Tensile Test.*—The material shall conform to the following requirements as to tensile properties.

Tensile strength max. lb. per sq. in., 55,000; min. lb. per sq. in., 51,000.
Yield point minimum lb. per sq. in., 25,000.

5. *Bend Test.*—The bend-test specimen shall bend cold through 180 degrees without cracking on the outside of the bent portion, around a pin the diameter of which is equal to the thickness of the specimen.
6. *Number of Tests.*—Two tension tests and two bend tests shall be taken from each heat, but not both tension or both bend tests from the same slab.
7. Sheets less than ¼ inch in thickness shall not be required to be stamped at the mill on account of the small size and light weight of the sheets.

5. *Test Coupons*—Seventeen tension test coupons were cut from tank No. 7. They were 12 in. long, and 1½ in. wide throughout the central portion 8 in. in length, and widening to 2 in. at a point 3½ in. from each end. They were cut transversely from the tanks so that the direction of the tension in these specimens was the same as that of the circumferential tension in the tanks. In making the tension tests the specimens were held in ordinary flat wedge-shaped grips in a 50,000-lb. testing machine.

Twelve of the coupons (A1 to A12) were cut from the tank so that the longitudinal seam was at the center of the specimen. The other five coupons (B7 to B11, inclusive) were cut from the tank plate and included no weld.

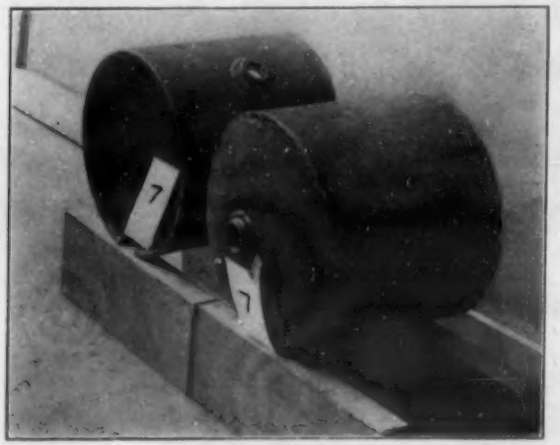


FIG. 1. CONVEX AND CONCAVE ENDS OF TANK NO. 7

In order to determine the relation of the strength of the weld to that of the plate per inch of width, seven of the specimens, A1 to A7, inclusive, had varying numbers of 1/16 in. holes drilled through the welds. Figs. 2 and 3 show the holes through the welds and show the location of the failure of the test coupons.

In four of the specimens strains were measured across the central section with Huggenberger tensometers over a gage length of 1 in. One tensometer was placed on each side of the specimen in order to make possible the determination of the average strain. In two of these four specimens, A11 and A12, a weld was included in the gage length. In the other two specimens, B10 and B11, there were no welds.

The stress strain curves plotted from these measurements are shown in Fig. 14. The elongation under load was greater for both types of specimen than should be expected with straight specimens, the apparent modulus of elasticity for the unwelded specimens being approximately 25,000,000 lb. per sq. in. The first thought is that the large deformation is due to straightening out of the specimens, but if this were the case a curved graph would be expected, whereas the graph is very nearly straight. The most unexpected feature of these tests is the fact that the strains were about twice as great in the welded as in the unwelded specimen for stresses below 10,000 lb. per sq. in., three times as great at 20,000 and nearly ten times as great at 30,000 lb. per sq. in.

With one of the welded specimens the load was released from 26,500 lb.

TABLE 1—RESULTS OF TENSION TESTS OF COUPONS FROM TANK NO. 7

Coupon No.	Thickness, In.	Width, In.	Sectional Area, Sq. In.	No. of Holes	Elongation in 2 In., Per Cent	Reduction in Area, Per Cent	Stress in Plate at Yield Point, Lb./In.†	Stress in Plate at Yield Point, Lb./Sq. In.	Stress in Plate at Maximum Load Lb./In.†	Stress in Plate at Maximum Load Lb./Sq. In.	Stress in Weld at Max. Load, Lb./In.†
B 7	.126	1.50	.189	0	35	51	5,180	41,000	6,800	54,000	
B 8	.126	1.525	.192	0	40	55	5,130	41,500	6,900	55,000	
B 9	.127	1.515	.192	0	38	52	5,050	39,800	6,900	54,500	
B 10	.126	1.515	.191	0	35	56			6,950	55,100	
B 11	.127	1.520	.192	0	35	60			6,820	53,900	
A 1	.125	1.495	.187	9	36	63	5,290	42,200	6,810	54,500	10,800
A 2	.126	1.545	.195	8			5,240	42,000	6,740	53,900	9,950
A 3	.125	1.551	.194	9	35	58	5,240	41,800	6,750	54,000	10,600
A 4*	.124	1.540	.191	9			5,170	41,800	6,440	52,000	10,100
A 5	.125	1.543	.193	9	35	51	5,130	41,000	6,780	54,200	10,600
A 6*	.124	1.501	.186	10			5,050	41,300	6,550	52,800	11,000
A 7*	.123	1.520	.187	10			5,150	41,600	6,530	53,000	11,000
A 8	.124	1.515	.188	0	34	56	4,930	39,700	6,860	55,100	6,830
A 9	.123	1.520	.187	0	35	51	5,090	41,400	6,800	55,300	6,800
A 10	.125	1.523	.190	0	32	61	5,120	41,000	6,800	54,300	6,780
A 11	.124	1.520	.187	0	32	54			6,850	55,600	6,860
A 12	.125	1.515	.189	0	33	61			6,950	55,600	6,950

*These specimens failed in the weld. All other welded specimens failed at least 3.5 in. away from the weld.
†Pounds per inch width of specimen.

Page Eight

Page Seven

per sq. in. to zero with a recovery of only 15 per cent of its elongation. The same stress was again applied and released and applied a third time. The enlarged portion of the stress strain curve shows that with the first and second releases of load the amount of recovery was almost identical, .0016 and .00163, respectively. With the second and third applications of load the amount of added strain was almost identical, .00193 and .00192.

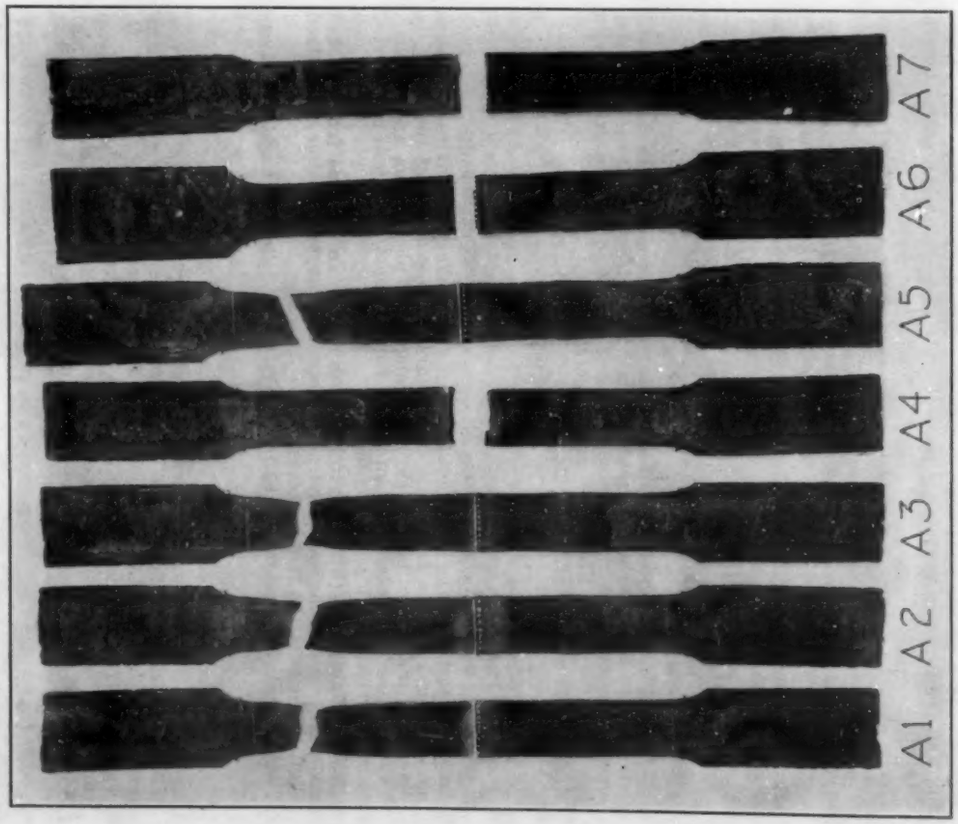


FIG. 2. WELDED COUPONS AFTER TEST

The apparent modulus of elasticity, even for the second and third applications of load, was not greater than 15,000,000 lb. per sq. in. This low computed modulus might be disturbing except for the fact that in the test of the tank the modulus was considerably higher, as reported in section 11.

tion 11.

The reason for the enormous difference in strains during the first application of load between the welded and unwelded specimens is unexplained. As the specimens were cut transversely from circular tanks, straightening of the specimens during loading will account for some of the excess deformation, but the shape of the curves is not such as to make this an entirely satisfactory explanation. Furthermore, it does not explain the great difference between the behavior of the welded and the unwelded specimens.

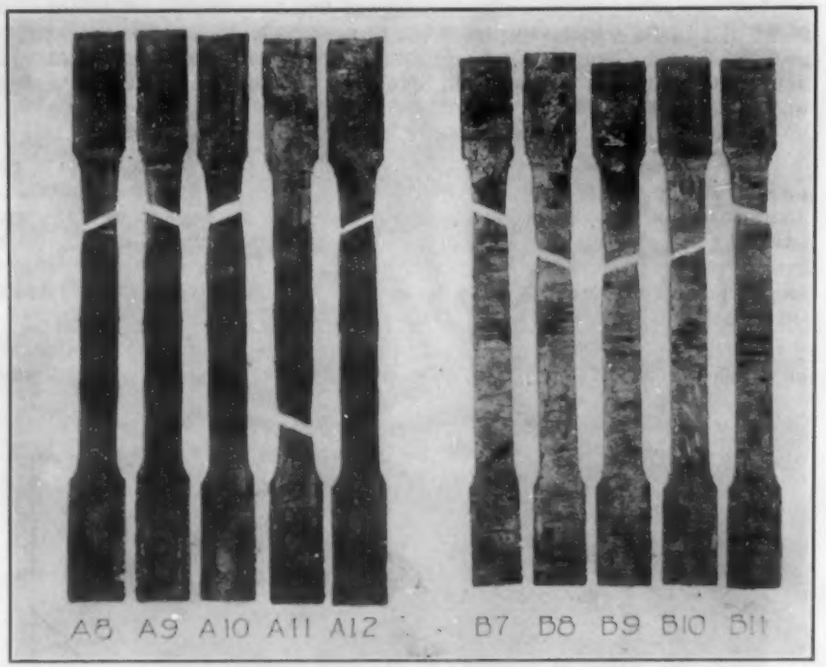


FIG. 3. UNWELDED COUPONS AFTER TEST

The results of the coupon tests are given in Table 1. The average strength of the specimens which failed in the plate was 54,500 lb. per sq. in. The average yield point for the plates was 41,200 lb. per sq. in. Of the four coupons which had nine 1/16-in. holes through the weld, three failed in the plate and one in the weld. Apparently with nine holes the strength was nearly balanced between the plate and the weld. The effective width of the weld was 60 per cent greater in the specimens which had no holes than in those which had nine holes. This would indicate that the strength per inch of the weld was 60 per cent greater than the strength per inch width of plate. The relative strengths may also be determined in a different way. The average strength of the plate for specimens which broke in the plate was 6800 lb. per inch of width. The average strength of the specimens which broke in the weld was 10,700

lb. per inch of width, which is 57 per cent greater than the strength of the plate. This is a good check of the 60 per cent excess strength determined in a different manner.

6. *Set-up for Hydrostatic Tests*—The set-up is shown in Fig. 4. The

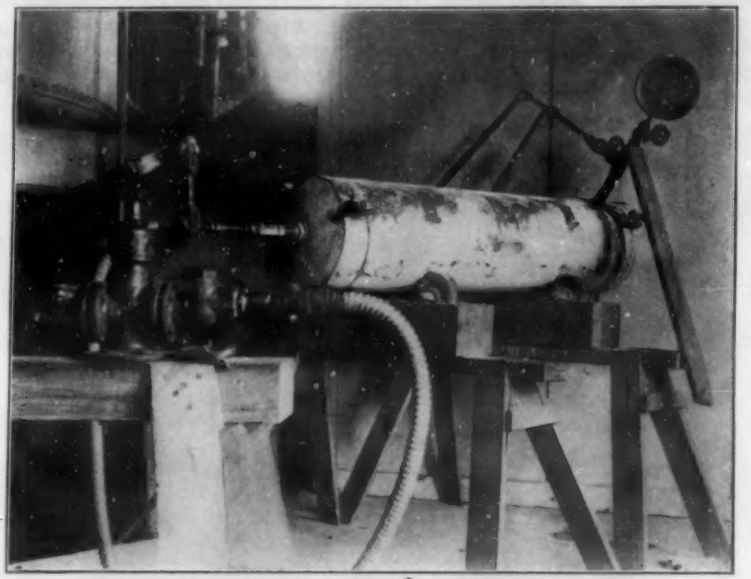


FIG. 4. SET-UP FOR HYDROSTATIC TEST

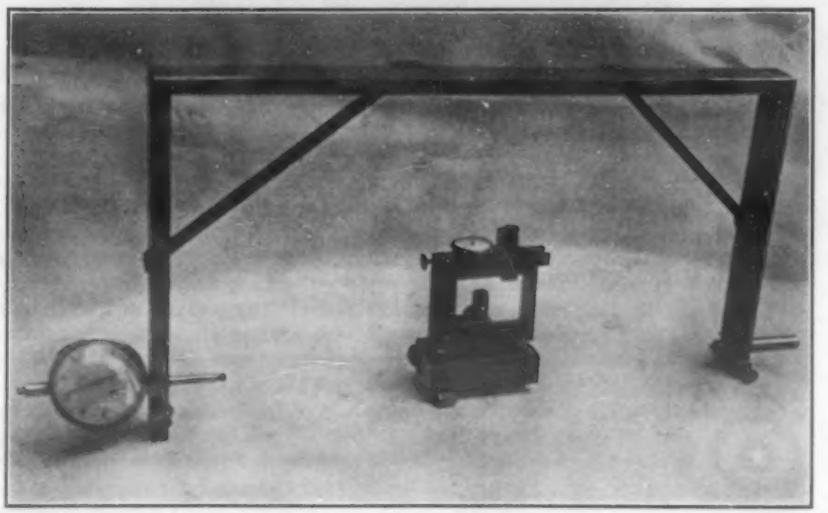


FIG. 5

hydrostatic pressure was applied by means of a hand pump attached to a city water pipe in the Fritz Engineering Laboratory. The pressure was measured by means of Lonergan hydraulic pressure gages with capacities of 500, 1000, and 2000 lb. per sq. in. For the lower pressures one of the smaller gages was used. When its capacity was reached the pressure

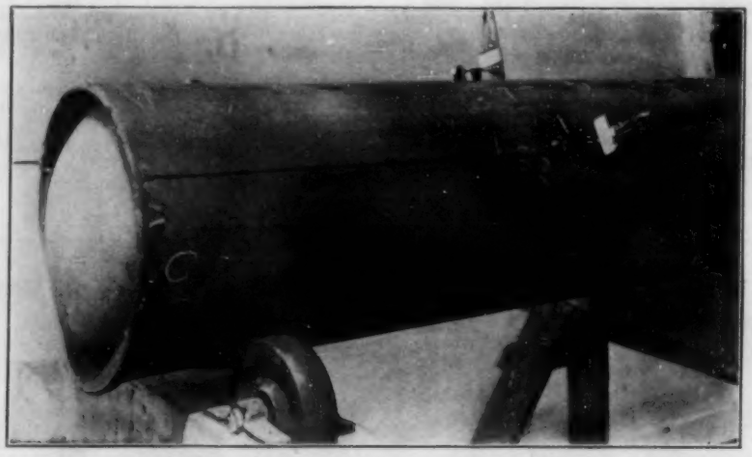


FIG. 6. TANK NO. 6, SHOWING HUGGENBERGER TENSOMETER IN PLACE

was released and the gage replaced with one of greater capacity. The gages were calibrated at Lehigh University.

7. *Measurements*—Measurements were taken of strain, change in diameter of shell, angular deformation in the transverse weld, and deflection of the heads. An attempt was made in the first tank tested, to use a whitewash coating to detect the development of strain lines. This was not very successful because part of the mill scale had been previously removed by a sand blast and because much of the whitewash was rubbed off in the process of taking readings.

The strains were measured with a 2-in. Olsen strain gage shown in Fig. 5 and with a Huggenberger tensometer of 1-in. gage length shown in Fig. 6. The tensometer was used only on tank No. 6. The strain gage measurements were taken transversely and longitudinally across the longitudinal welds and in the plates in the gage lines 1 to 7, and 11 to 18 as shown in Fig. 13 for tank No. 1. For the other tanks fewer strain gage measurements were taken, but the numbering and position of those taken correspond with the layout in this figure.

The diameter changes were measured by means of an outside caliper equipped with an Ames gage graduated to thousandths inches and having a travel of 1 in. The caliper is shown in Fig. 5. The diameter changes were measured at the points shown as solid circles in Fig. 13 and numbered 1 to 7, and 11 to 17, inclusive. The diameters 1 to 7 were at right angles to 11 to 17 respectively. The latter lay on a diameter passing through the weld.

In the measurement of angular deformations in the transverse welds two metal "fingers" were welded to the metal of the shell as close as possible to and on opposite sides of the weld. The fingers projected several inches from the weld and to one of them an Ames gage was attached with its plunger bearing upon the other finger. Angular movement in the weld caused the fingers to spread apart or to move toward each other, and the amount of movement was measured by the Ames gage. The change in angle between the fingers was assumed to be the same as the angular change in the weld. This is not exactly true, since any bending in the plate between the weld and the point of attachment of the fingers would increase the change of angle between the fingers. It is believed, however, that this effect was not large. From the amount of movement and the distance from the weld at which it was measured, the angular change was computed. The device for measuring angular deformations is shown in Figs. 7 and 8. The angular deformations were measured at three or four points approximately equally spaced around the circumference of the tanks at the transverse weld, as shown in Figs. 4, 7, 8 and 13.

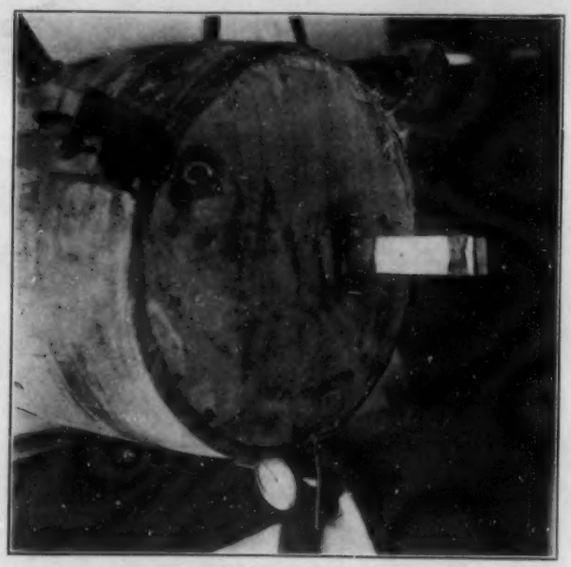


FIG. 7. DEVICE FOR MEASURING ANGULAR DEFORMATION IN WELDS AND SCALE FOR MEASURING END DEFLECTION

End deflection of the center of the head was measured to hundredths inches by means of a paper scale attached to a standard, welded to the head as shown in Fig. 7. Metal strips attached to the shell at opposite ends of a diameter carried a No. 36 wire which passed in front of the paper scale. Parallax in reading the position of the wire on the scale was avoided by lining up the wire with its image in a mirror which was attached to the paper scale.

For measurement of deflection of the concave heads at points away from the center, a metal bar was supported across the concave end of the

through the weld.

from the center, a metal bar was supported across the concave end of the

tank, as shown in Fig. 8. The distance from the bar to the head was measured with a depth gage at 1-in. intervals along the diameter.

8. *Procedure in Testing*—The readings in all the measurements were taken by M. O. Fuller or by other members of the staff of Fritz Engineering Laboratory. Mr. A. T. Snow of the John Wood Manufacturing Company was present during all of the tests.

The general procedure in testing was to take full sets of readings on all instruments before any pressure was applied, and again after each of several increments of pressure had been applied. At more or less frequent intervals the pressure was released and readings were taken to determine the amount of the permanent set, if any existed. Usually the strains

FIG. 8. BAR FOR MEASURING BULGING OF HEAD

exceeded the range of the strain gage before the maximum load was reached.

At pressures of 600 lb. per sq. in. and greater for tanks Nos. 1 and 5, having both ends convex, the welds were hammered vigorously.

The test of tank No. 1 was more or less in the nature of a pilot test and the tests of later tanks were varied according as the results from this test indicated that some of the measurements were either inadequate or unnecessary.

A detailed description of the testing of tank No. 1 is given in section 9 as typical of the procedure followed in all the tests. Details for the remaining tests are not given.

9. *Testing of Tank No.* 1.—Tank No. 1 was tested on August 6 and 7. Initially, connections from the pump to the tank were made through a reinforced hose, as shown in Fig. 4. The connection gave some trouble and caused more violent release of pressure than had been planned. For the higher pressures a pipe connection was substituted. Pressures of 67, 133, and 200 lb. per sq. in. were applied successively with full sets of readings at each pressure. The pressure was then released to zero and another set of readings taken. It was then increased successively to 267, 333, and 400 lb. per sq. in., then reduced to zero and readings taken again. The pressure was then increased to 500, 600, and 700 lb. per

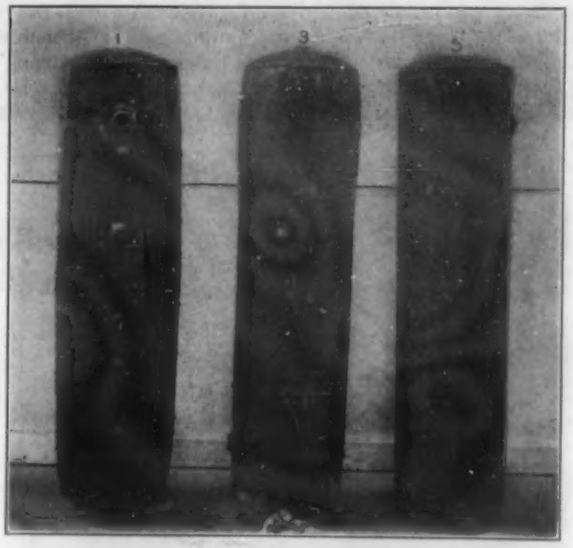


FIG. 9. TANKS NO. 1, 3 AND 5 AFTER TEST

sq. in., successively. At the last named pressure the strain at most places exceeded the range of the strain gage. At a pressure of 700 lb. per sq. in. a pin-hole leak started in the weld at the north end, between the dials marked A and B. At this time the hose slipped off the pump and released the pressure. After repairs had been made the pressure, 700 lb. per sq. in., was reapplied. The leak in the pin-hole apparently closed after this pressure had been held for a few minutes. At 750 lb. per sq. in. it started again with a very fine misty spray. The pressure was then raised to 880 lb. per sq. in. Under this pressure the longitudinal weld was hammered vigorously with a hammer weighing 1⅝ lb. The hammering was hard enough to dent the metal. Peening of the weld metal at the pin-hole stopped the leakage. Pressure was then increased to 920 lb. per sq. in. without further leakage. Leakage around the hose

connection was so great that the pressure could not be raised above 920 lb. per sq. in. The hose slipped off the pump again and the testing was discontinued for the day.

On August 7, after refitting the connection with pipe, pumping was started again at 9.30 a. m. During this pumping mill scale flaked very rapidly. It was evident to the eye that the tank was expanding. At this stage the floor was littered with mill scale which had dropped from the tank. Most of this scale came from the shell, as the ends of the tank showed little or no scaling. The pieces of scale which flaked off were much elongated in the direction of the axis of the tank. A strip of the shell, about 6 in. wide (3 in. each side of the longitudinal weld) showed little or no scaling. Also a band somewhat wider, about 180 deg.

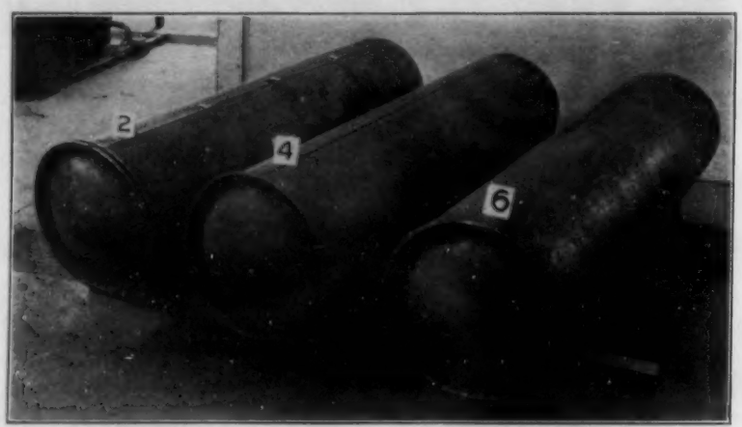


FIG. 10. TANKS NO. 2, 4 AND 6 AFTER TEST; END VIEW

from the weld, showed less than the average scaling. A strip of metal from 1½ to 3 in. wide, along each of two opposite edges of the sheet which formed the shell, had been sand-blasted prior to fabricating the tank. As these two edges were brought together to form the seam of the tank, the sand-blasting may account for the 6-in. band in which no flaking was observed. The small amount of flaking which was observed about 180 deg. from the longitudinal weld is not accounted for. However, more extensive flaking of this latter strip occurred under further application of the maximum pressure.

After reaching an indicated gage pressure of 1000 lb. per sq. in., the pipe fittings broke and the pressure was lost. At the time that the pipe fitting broke the longitudinal weld and the ends of the tank were being hammered. With the pressure released, readings of the diameter changes were taken. These readings indicated that due to the permanent elongation of the metal there was an average increase of 0.52 in. in the diameter passing through the longitudinal weld and of 0.53 in. in the diameter at right angles to the former.

The break in the pipe line was then repaired and the pressure reap-

plied. The longitudinal welds and both heads were pounded as hard as possible with the 1⅝-lb. hammer under water pressures of about 600, 800, and 1000 lb. per sq. in. This pounding included the point in the north head at which a pin-hole leak had occurred earlier in the test. No effect of this pounding was observed. The pressure was then released to about 300 lb. per sq. in. and raised again, pounding as before, when the pressure got up to about 800 lb. per sq. in. and above.

FIG. 11. TANKS NO. 2, 4 AND 6 AFTER TEST; SIDE VIEW

At a pressure of 980 lb. per sq. in. a very small leak appeared through a gage hole at about 90 deg. from the longitudinal weld. At this time the gage hole had been much elongated due to the deformations of the metal, and this probably is responsible for its opening. The pumping was discontinued, but the city water pressure of about 50 lb. per sq. in. was left on. Under this condition, lowering of the water pressure took place slowly. A thin spray escaped from this hole until after about 5 min. the pressure still stood at nearly 200 lb. per sq. in.

After releasing the pressure, diameter measurements were taken again. At the ends of the tank (stations 1, 7, 11, and 17) the average change in diameter was still only 0.082 in., but at all other stations the increase of diameter had been so great that it could not be read with the micrometer. Measurement of the circumference showed an increase in diameter of about 1 in.

At this time scaling had reached all parts of the shell and around the pipe entrance in the center of one head. Other parts of this head showed no appreciable scaling. The other end showed only slight scaling and this at isolated spots. The tank was still without leakage except at the opening through the gage hole of strain gage station No. 13. This hole could

have been repaired by peening or welding, and the test continued. However, as the pressure gage had a capacity of only 1000 lb. per sq. in., no higher pressure could be measured with this gage, and the test was discontinued. A recalibration of the pressure gage after the completion of the test indicated that the actual pressure required to produce an indicated pressure of 1000 lb. per sq. in. was approximately 1100 lb. per sq. in.

The pointer of the gage had apparently been disturbed by the sudden release of pressure when the pipe connections failed, so it is likely that the higher pressures were about 100 lb. per sq. in. greater than those reported. In the later tests no difficulty was experienced due to failure of connections.

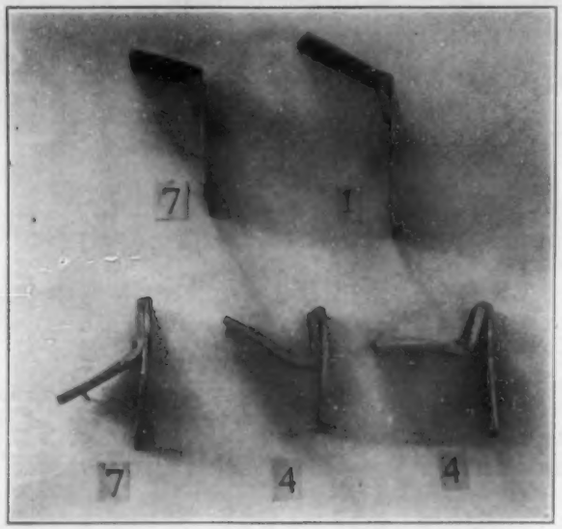


FIG. 12. SECTIONS THROUGH TRANSVERSE WELDS OF TANKS NO. 1, 4 AND 7

Later, a pressure gage having a capacity of 2000 lb. per sq. in, was secured and connected to tank No. 1 and the gage holes were closed by welding. Pressure was then applied and failure occurred at a pressure of 1185 lb. per sq. in., tearing a longitudinal hole 11 in. long, along an element of the cylinder about 113 deg. (13 in.) from the longitudinal weld. Failure away from the weld confirmed the showing from the coupon tests, that the weld was stronger than the plate. The appearance after failure is shown in Fig. 9. In this view the longitudinal weld is at the extreme left and it may be seen that the rupture is somewhat more than 90 deg. from it.

10. *Principal Features of Tests*—No other tank than No. 1 failed with rupture along a longitudinal element either in the weld or in the plate. Tanks Nos. 3 and 5, both ends convex, failed by leakage through the transverse weld. An effort was made to repair the leaks so that enough pressure could be developed to cause pronounced failure. This was not

successful, and in neither case was failure complete. In tank No. 3, however, a pronounced bulging was developed near one end, as may be seen in Fig. 9. The maximum pressures carried by tanks Nos. 3 and 5 were 860 and 1075 lb. per sq. in., respectively.

The failure of tanks Nos. 2, 4, and 6, concave at one end, were characteristically different from those of tanks Nos. 1, 3, and 5. There were two distinct stages in the failure of the former, namely, the buckling and bulging of the concave head, followed by rupture of the transverse weld at the concave head. In the case of tank No. 2 a pressure of 600 lb. per sq. in. was developed with no appreciable difference in behavior from that of tanks Nos. 1, 3, and 5. After holding this pressure for a few seconds the concave head began to bulge at the center. The pressure fell off to 300 lb. per sq. in. In the meantime some pumping had been done

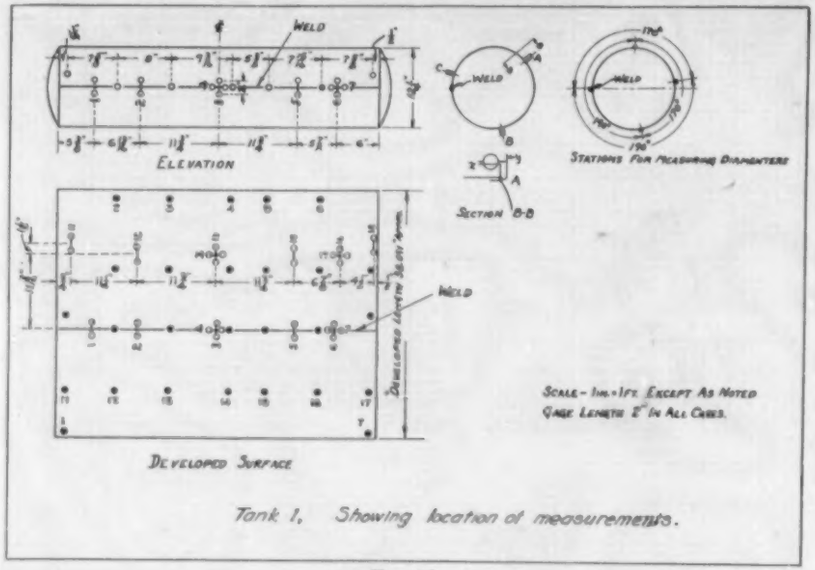


FIG. 13

in an effort to maintain the pressure. Under these conditions the center of the head had deflected about 1⅛ in. At this time the bulged part of the head had the form of a saucer convex outward and having a diameter of 5¾ in. The pressure was then increased to 360 lb. per sq. in., and during this operation the center deflection had increased to about 2.9 in. and the diameter of the bulged portion had increased to 10 in.

The pressure was then increased to 560 lb. per sq. in., when a leak appeared in the transverse weld at the concave head. At 600 lb. per sq. in. the leak became pronounced and the center had bulged to 1 in. beyond the end of the shell. From this time on, the pressure continued to fall, due to leakage and at 460 lb. per sq. in. the transverse weld ruptured for a distance of about 10 in. (90 deg.) on each side of the longitudinal weld. The longitudinal weld was not fractured at any point although

the end had enlarged to 12.4 in. in diameter. The condition of the tank as it appeared after the test, is shown in Figs. 10 and 11.

In tanks Nos. 4 and 6 the pressure when bulging began was 740 and 760 lb. per sq. in., respectively. The pressure fell off promptly and later was raised to 680 and 600 lb. per sq. in. in the two tanks, respectively, when fracture in the transverse weld took place. The behavior of these tanks differed from that of tank No. 2 in that the maximum pressure developed was that at which bulging began.

Table 2 summarizes, for a pressure of 500 lb. per sq. in. the stresses, the diameter changes, the end deflections, and the angular deformations. It gives also the maximum pressures developed in the tests.

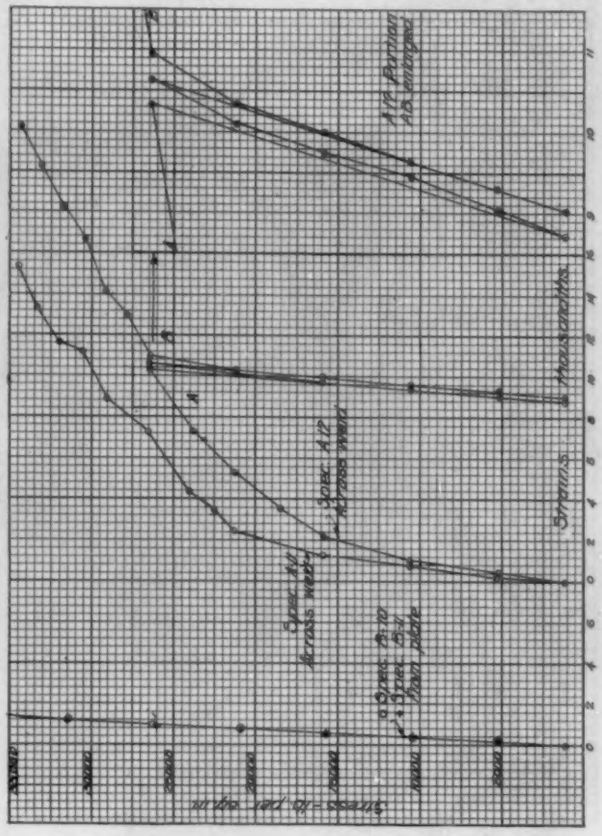


FIG. 14. STRESS STRAIN GRAPHS FOR TRANSVERSE COUPONS FROM TANK 7

The pressure of 500 lb. per sq. in. was selected for this comparison because it was the highest pressure within what appeared to be the elastic range, for which information could be obtained. The average of the maximum pressures developed, was 700 lb. per sq. in. for the tanks in which one end was concave and 1040 lb. per sq. in. for those in which both ends were convex. Discussion of the stresses, diameter changes, deflections, and angular deformations is found in succeeding paragraphs.

11. *Strains*—The transverse strains have been plotted in Fig. 15. The solid line and solid circles indicate the strains under load, and the dotted lines and open circles indicate the residual strains under no load. Each open circle indicates the strain when the pressure was reduced to zero from that pressure opposite which the point is plotted.

It was found, as was to be expected, that the strains in the transverse

TABLE 2—SUMMARY OF OBSERVED VALUES FOR PRESSURE OF 500 LB. PER SQ. IN. AND OF MAXIMUM PRESSURE CARRIED

Tank No.	Transverse Stress Across Weld, Lb./In.²	Transverse Stress In Plate, Lb./In.²	Longitudinal Stress in Plate, Lb./In.²	Diameter Through Weld, In.	Change Normal to Plane Through Weld, In.	End Deflection South In.	End Deflection North In.	Angular Deformation Convex Heads, Deg.	Angular Deformation Concave Heads, Deg.	Maximum Pressure, Lb./In.²
1	37,300	21,000	6,600*	−.02	+.003	.06	.01	1.2		1,185
2	29,700	30,400	12,300	+.01	−.031	.06	.06**	1.3	.03	600
3	28,200	17,600	6,600	−.005	−.003	.02	.03	0.5		860
4							.03**			740
5	23,000	22,000	7,500	+.007	−.002	.05	.04**	0.4		1,075
6							.05			760

*Secured by extrapolation from readings taken up to and including 400 lb. per sq. in.
**North end concave for Tanks 2, 4 and 6. All others convex.

gage lines 1, 6, 11, 16, and 18, near the end of the tank were smaller than those nearer the center. These gage lines were omitted from consideration in Fig. 15 since it is the larger strains that are critical in the strength of the tank. In the upper part of Fig. 15 the average strains in gage lines 2, 3, and 5 (except that in tank No. 2 gage line 5 was missing), across the longitudinal weld, are shown for individual tanks, and the average of these averages for all the tanks.

Transverse strains in the plate away from the weld were measured in gage lines 11, 12, 13, 15, 16, and 18, in tank No. 1, but only in gage line

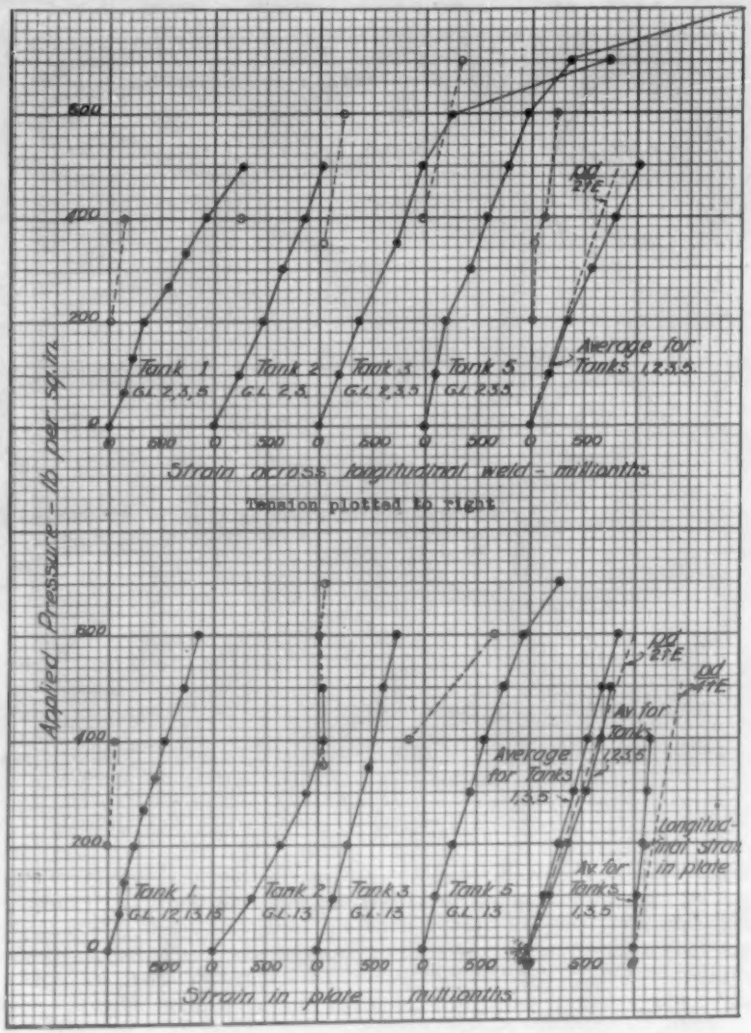


Fig. 15. Transverse Strain in Tanks 1, 2, 3 and 5 from Strain Gage

It was found, as was to be expected, that the strains in the transverse

13 in tanks Nos. 2, 3, 5, and 6. In the lower part of Fig. 15 the curve of transverse strains for tank No. 1 is the average for gage lines 12, 13, and 15. For each of the tanks Nos. 2, 3, and 5, the curve is for the single gage line 13. The four curves so obtained have been averaged to give the curve of average transverse strains in the plate. It will be noted that the strains for tank No. 2 were in most cases more than twice as great

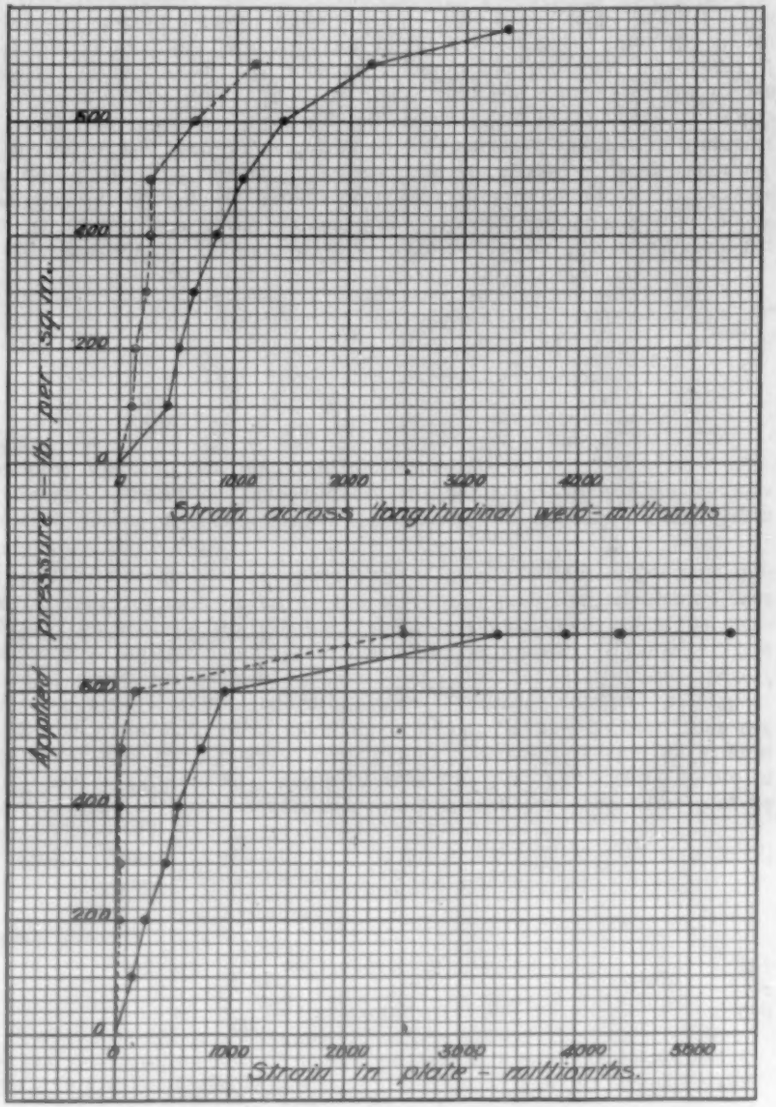


Fig. 16. Transverse Strain in Tank 6 from Huggenberger Tensometer

as the transverse strains in the plate of any other tank. This raises some doubt as to the propriety of including tank No. 2 in the average. To show the effect of the large strains in tank No. 2, the average for tanks Nos. 1, 3, and 5 is plotted from the same origin as that for tanks Nos. 1, 2, 3, and 5. If tank No. 2 be omitted from the average it will be seen that the average transverse strain in the plate was slightly smaller

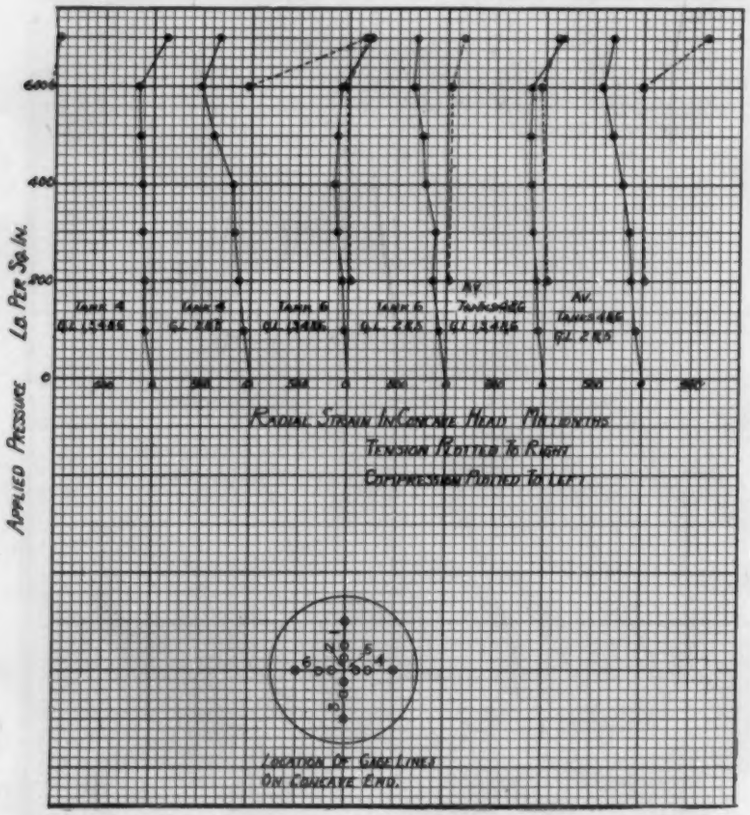


FIG. 17. RADIAL STRAIN IN CONCAVE HEAD FOR TANKS 4 AND 6

than the average transverse strains across the welds. If tank No. 2 be included in the average, the strains in the plates were almost the same as those across the welds for pressures up to about 300 lb. per sq. in. In either case, the difference between the transverse strains in the plate and that across the welds was much less than that found with the Huggenberger instrument, as between welded and unwelded tension test coupons. The gage length of the Huggenberger instrument was only 1 in. and that of the strain gage was 2 in. Any elongation in the weld would therefore make a greater showing in the strains determined with the former than with the latter instrument.

The straight dotted lines drawn at the right in Fig. 15 give the transverse and longitudinal strains computed from the ordinary formulas:

$$e = \frac{pd}{2\,tE} \text{ for transverse strains,} \quad (1) \text{ and}$$

$$e = \frac{pd}{4\,tE} \text{ for longitudinal strains} \quad (2)$$

In these formulas e is strain
p is pressure
d is diameter of tank
t is thickness of tank
and E is modulus of elasticity of the steel, here taken as equal to 29,000,000 lb. per sq. in.

The longitudinal strains were measured in tank No. 1, in gage lines 14 and 17, and in tanks Nos. 3 and 5 in gage line 14. The strains found in these gage lines have been averaged, and the result plotted as a solid line in the lower right-hand part of Fig. 15. It will be seen that the transverse strains computed by formula (1) were smaller than those measured across the weld and larger than those measured in the plate if tank No. 2 is omitted from the average for the plates. If tank No. 2 is included, the average for the plate is in fair agreement with the computed strains. The average of the measured longitudinal strains was less than half of those given by formula (2). The reason for this disagreement is not known.

Solving for E in formula (1), the modulus of elasticity found from the average slope of the stress strain curves of Fig. 15 for the various tanks is as given in the following tabulation:

Tank No.	Modulus of Elasticity from Measured Strains	
	Across Weld	In Plate
1	20,600,000	34,600,000
2	23,600,000	16,800,000
3	24,500,000	38,400,000
5	31,200,000	30,700,000
Average	25,000,000	30,100,000

The variation in the moduli as determined from the strains in the plate is seen to be very great. Values above 31,000,000 and below 28,000,000 lb. per sq. in. are to be regarded with suspicion. There is little doubt that the strains on which they are based, actually occurred, but in view of the peculiar variation of the measured changes in diameter it is likely that the stresses for a given pressure varied considerably in different parts of the tank. It seems likely that the average of the values is not far from correct. It must be remembered, too, that in several of the tanks the modulus determination in the plate is based upon the strain in only one station, namely, gage line 13. This probably accounts for the fact that the variation among the values determined for the plate is greater than that found across the weld. The transverse strains measured in tank No. 6 with the Huggenberger tensometer are shown in Fig. 16. One of the instruments measured the strains across the weld, and the other measured those in the plate about 90 deg. from the weld, as shown in Fig. 6. It is found here also that the strains across the weld were greater than those in the plate. The modulus of elasticity for the plate, computed from these strains and formula (1), is 32,800,000 lb. per sq. in.

therefore make a greater showing in the strains determined with the former than with the latter instrument.

greater than those in the plate. The modulus of elasticity for the plate, computed from these strains and formula (1), is 32,800,000 lb. per sq. in.

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It is difficult to determine a modulus from the strains across the weld, but a computation based upon the average slope of the stress strain curve gives 22,600,000 lb. per sq. in. as the modulus.

In this case the load was released after each pressure increment of 100 lb. per sq. in., and the resulting curve of permanent set, shown with open circles and dotted lines, is the most definite that was secured in the tests. The permanent set across the weld was pronounced at very low pressures. In the plate it was not appreciable until a pressure of 500 lb. per sq. in. (computed stress 24,000 lb. per sq. in.) was reached and from then on it increased rapidly.

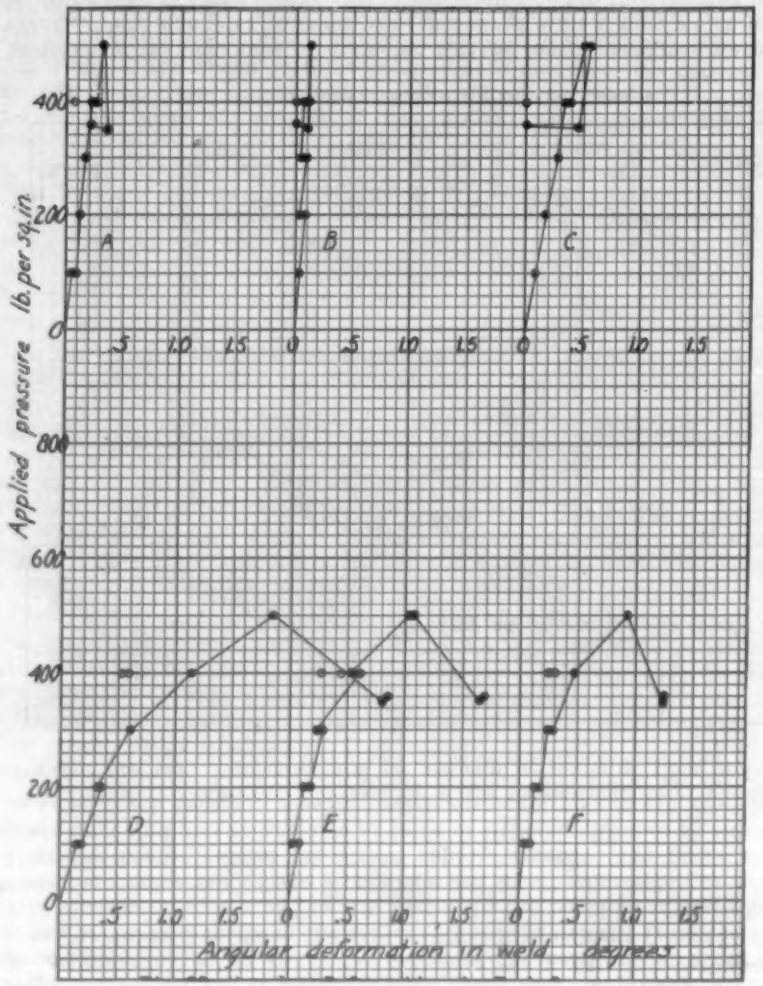

FIG. 18. ANGULAR DEFORMATION IN TANK 2; A, B AND C CONVEX END D, E AND F CONCAVE END

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Readings of residual strains, with the strain gage, after releasing the pressure were not taken at sufficiently frequent intervals to permit a determination as to when permanent strain first appeared. The values which are given in Fig. 15, however, indicate that at 500 lb. per sq. in. the permanent strain was very small.

The radial strains in the concave heads of tanks Nos. 4 and 6 have been plotted in Fig. 17, grouped according to position on the head. It will be seen that all the strains were in compression until a pressure of 700 lb. per sq. in. was reached. At this pressure the concave heads were near buckling and a complete change in behavior was imminent. The compression was greater in the gage lines which crossed the center of the head than in those away from the center. The maximum strains shown

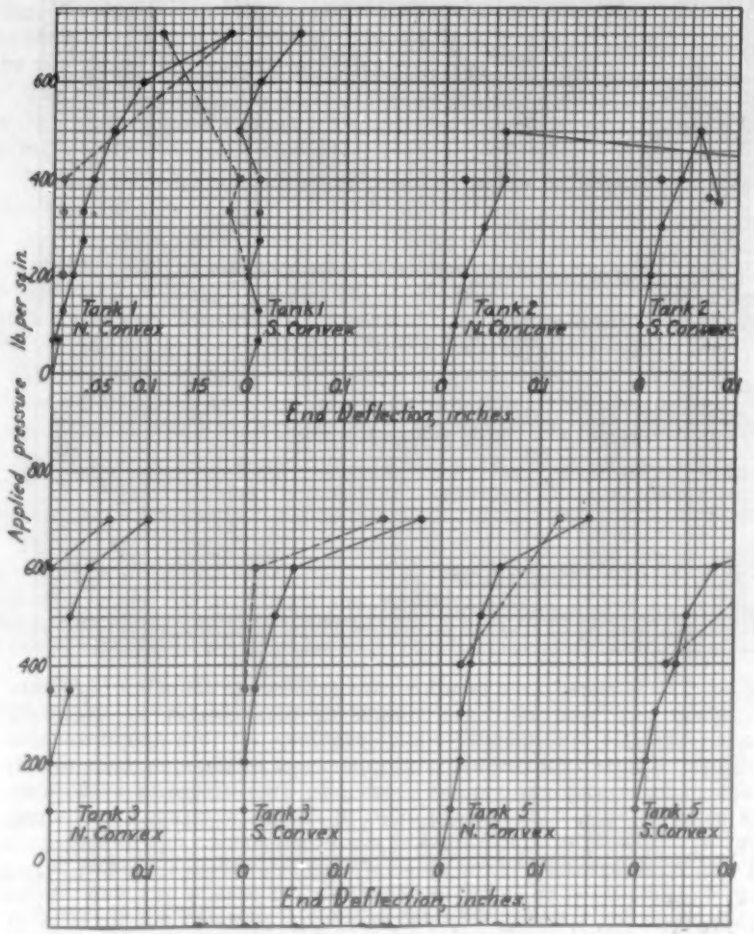
Applied pressure lb. per sq. in.
Tank 1 N. Convex
Tank 1 S. Convex
Tank 2 N. Concave
Tank 2 S. Convex
End Deflection, inches
Tank 3 N. Convex
Tank 3 S. Convex
Tank 5 N. Convex
Tank 5 S. Convex
End Deflection, inches

FIG. 19—CENTER DEFLECTION OF ENDS OF TANKS 1, 2, 3 AND 5

in the average curves at the right correspond to a compressive stress of about 12,000 lb. per sq. in. at the center of the head and of about 4000 lb. per sq. in. at 3 in. from the center. It will be evident from the shape of the heads, as shown in Fig. 10, that with the buckling of the concave heads the strains at all these points changed from compression to tension. After the heads buckled the strain rapidly exceeded the range of the strain gage and was so unstable as to be of little significance at any time.

12. *Diameter Changes*—The results of the measurements of change in diameter are very confusing and no use can be made of them unless it

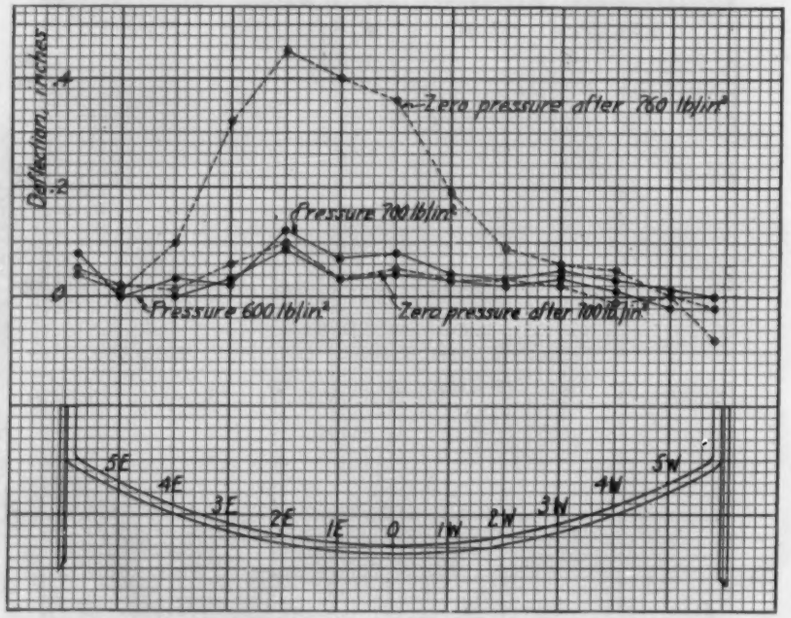

FIG. 20—DEFLECTION OF CONCAVE END OF TANK 4

be to show that changes of diameter for the lower pressures were very erratic. The diameter changes were measured with a gage which at best could be read to thousandths and by estimation to ten thousandths inches. With the hope of securing a direct comparison with the results of the transverse strains measured with strain gage, the diameter changes were reduced to change per inch of diameter; that is, to strains. However, the lack of sensitiveness of the Ames gage, and the difficulty of replacing the caliper for successive readings at the same station, conspired to make the curves of diameter change very irregular. However, the trend of the curves is sufficiently consistent to indicate that the difficulty was not entirely that of lack of accuracy. Some of the curves† indicate an increase and others a decrease in diameter. The measurements of stations 11 to

†Diagrams showing change in diameter and two of the three showing angular deformations have been omitted.

16 were in the plane of diameters passing through the weld, and those on stations 1 to 6 were perpendicular thereto. It is conceivable that due to the lack of homogeneity the diameter might decrease in certain places, even though the transverse stress is everywhere in tension. In fact, the finding of transverse strains in some places which were so much greater than those in others may be merely another manifestation of the same irregularity in behavior as is exhibited in diameter changes. However, it seems unlikely that the decrease should predominate over the increase in diameter, as is indicated in some cases. At best, the result of the measured diameter changes is a conundrum.

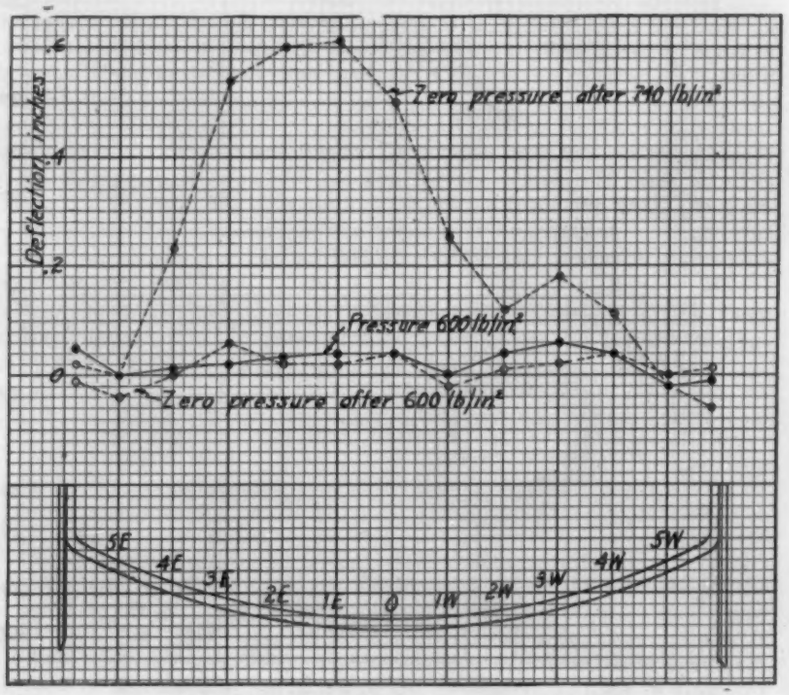

FIG. 21. DEFLECTION OF CONCAVE END OF TANK 6

13. *Angular Deformation*—The angular deformations, determined as described in section 7, have been plotted †in Fig. 18, for tank No. 2. The solid curves represent the angular deformation in degrees in the transverse weld, and the open circles represent the permanent set. Each open circle curve represents the residual deformation when the pressure was reduced to zero from the pressure opposite which the point is plotted.

It does not seem possible to convert the angular deformation measured into terms of stress because of the difficulty in determining the gage length over which the measurements were taken and because of the

†Diagrams showing change in angular deformation for two of the three tanks for which measurements were taken have been omitted.

†Diagrams showing change in diameter and two of the three showing angular deformations have been omitted.

†Diagrams showing change in angular deformation for two of the three tanks for which measurements were taken have been omitted.

extreme variation of the section within the gage length. However, the straightness of the graphs for the welds at the convex ends indicates that the strains were largely elastic up to a pressure of, say, 500 lb. per sq. in. This is further indicated by the fact that in cases where the load was reduced to zero, the permanent set was very small for loads below about 500 lb. per sq. in.

The angular deformation on the welds for the concave end of tank No. 2, as shown at D, E, and F, Fig. 18, gave curves which were less straight than those for the convex end. Also, the permanent set was quite large for a pressure of 400 lb. per sq. in. It is to be expected that permanent set at this point would begin at an earlier stage with this type of end, and that it would be greater than with the convex end.

In Fig. 12 are shown sections of specimens cut from the ends of the tanks at both convex and concave ends. The specimens of the convex and concave heads of tank No. 7 illustrate the appearance of these two types of head before test. Pronounced permanent angular deformation is seen in one of the specimens cut from the concave end of tank No. 4 after the test. It is evident that the deformation was largely, if not wholly, in the weld, since the plate shows no bending in the close vicinity of the weld. In the other specimen from tank No. 4 no angular deformation is apparent. The specimen from tank No. 1 is consistent with the showing in Fig. 18 of no permanent angular deformation in the transverse weld at the convex end.

14. *End Deflection*—The center deflections of both convex and concave ends of tanks Nos. 1, 2, 3, and 5 are shown in Fig. 19 by solid lines. The permanent set is indicated by dotted lines and open circles. The deflections at various points on a diameter of the concave end of tanks No. 4 and of No. 6 are shown in Figs. 20 and 21. The deflections of the concave end of tank No. 2 at loads below which bulging occurred, did not greatly exceed the deflections of the convex end. The center deflections of the concave end of tanks Nos. 4 and 6 were each 0.04 at a pressure of 600 lb. per sq. in. and this is less than the deflection of the convex end of any other tank at that pressure except at the north end of tank No. 3.

Figs. 20 and 21 show that up to the time that bulging took place the deflection of the concave ends of tanks Nos. 4 and 6 were very symmetrical with respect to the center. When bulging took place the deflection was very large and quite unsymmetrical. This lack of symmetry is shown also in Fig. 10.

15. *Summary of Results*—From the tension test coupons it was found that the transverse strength through the weld was 57 to 60 per cent greater per inch of width of specimen than at sections of the unwelded plate.

The tensile deformation in a one-inch gage length across the weld was greater than that in an equal gage length in the unwelded plate. This result was found both for the tension coupons with the Huggenberger tensometer, and for the transverse strains in the tanks. The difference in strain at the two places was greatest in the tension coupons.

The permanent set was very much greater in the welded than in the unwelded coupons. Also, as measured with the Huggenberger tensometer,

the transverse permanent set was greater across the longitudinal weld of the tank than that in the unwelded part of the plate.

The tanks with convex heads at both ends stood a great deal of abuse. Tank No. 1 carried a pressure of 1185 lb. per sq. in. after having been subjected to hammering the weld while under a pressure as high as 1000 lb. per sq. in. This hammering was severe enough to dent the metal of the tank.

The failure of the tanks with one end concave was distinctly different from that of the tanks with convex heads at both ends. In the former, the first phenomenon of failure was the buckling and bulging of the concave head. With the buckling the pressure fell off markedly and then rose as pumping continued. In one of the tanks of this type the maximum pressure was greater than that at which buckling started. In the other two it was not possible to recover this pressure. Final failure was by rupture of the transverse weld at the concave end.

The transverse strains in the plate of the tanks showed fair agreement with the computed strains. The strains crossing the longitudinal weld transversely were somewhat greater than the computed strains.

The measured longitudinal strains were less than half the computed longitudinal strains.

Permanent set in the plate of the tanks apparently began at a pressure of about 500 lb. per sq. in. when the computed stress was 24,000 lb. per sq. in. As indicated by the Huggenberger tensometer, permanent set across the weld for tank No. 6 began at a pressure much lower than 500 lb. per sq. in.

The radial strains in the concave head were compression up to the pressure which caused buckling and bulging. The strains across the center were greater than those 3 in. away from the center.

The diameter changes within the range of elastic behavior were very erratic. They indicated that in some places the diameter decreased even though the shell was in tension.

The angular deformations in the welds indicated elastic behavior up to a pressure of about 500 lb. per sq. in. for the convex heads. With the concave heads the permanent set was quite large at 400 lb. per sq. in. No distortion at the weld could be detected visually in sections cut from a convex head.

There was no apparent distortion of the convex heads at failure, while that of the concave heads was very marked.

The deflection of the concave heads up to the time of buckling and bulging was very nearly equal to that of the convex heads. From that time on it was enormously greater than that for the convex heads.

For pressures below that causing buckling the deflection was quite symmetrical about the center. After buckling started much eccentricity developed.

No weakness developed in the weld before the plates had shown signs of yielding. The only tank to fail along a longitudinal element was tank No. 1, and this failure was in the plate about 13 in. from the weld.

Notes on Macrographs and Micrographs from Seams of Welded Pressure Tanks

Made by

John Wood Manufacturing Company

By Wilber E. Harvey

MACROGRAPHS

THE macrographs which are included in this report were etched in accordance with methods accepted as standards, namely: 50% HCl—50% H_2O solution. They were etched for 15 minutes with the etchant at a temperature of 180 deg. Fahr.

In the examinations of the macrographs it must be kept constantly in mind that any defect which may be shown up by the deep etch will be greatly magnified by the deep etch with respect to the size of the original defect. While the magnification of the macrographs is three diameters, it must be recognized that a gas hole which is shown by a macrograph is somewhat less than one-third of the size shown by the macrograph.

The purpose of macrography is to reveal heterogeneity of the metal under test. This heterogeneity may be of three kinds; crystalline heterogeneity, mechanical heterogeneity and chemical heterogeneity.

MICROGRAPHS

The micrographs in this report are all magnified one hundred diameters. Each of the specimens was etched in a 10% HNO_3 solution in alcohol for varying lengths of time dependent upon the type of structure to be examined.

In the micrographic study of the seam welds it was necessary for permanent record to photograph three sections of the metal since three very definitely different structures were encountered with each weld. These structures are present in different forms due to the temperature to which the different parts were exposed and also due to the speed of cooling from whatever temperature to which they were exposed.

In the weld itself the metal was heated to a very high temperature and a large grain structure results due to (1) the high temperature, (2) the slow cooling of the metal from the high temperature.

Intermediate between the weld and the normal metal of the tanks is found a section of metal which had been heated to a fairly high temperature by the welding process although not exposed to anywhere nearly as high a temperature as the weld itself. The temperature was high enough to produce a fine grain size in the metal and this fine grain size was retained by the rapid cooling to which it was subjected.

*Metallurgical Department, Lehigh University.

This rapid cooling was promoted by the chilling effect of the large amount of cold metal adjacent to the heated section.

The third type of structure is the original metal structure, and this is characteristic of the type of metal used.

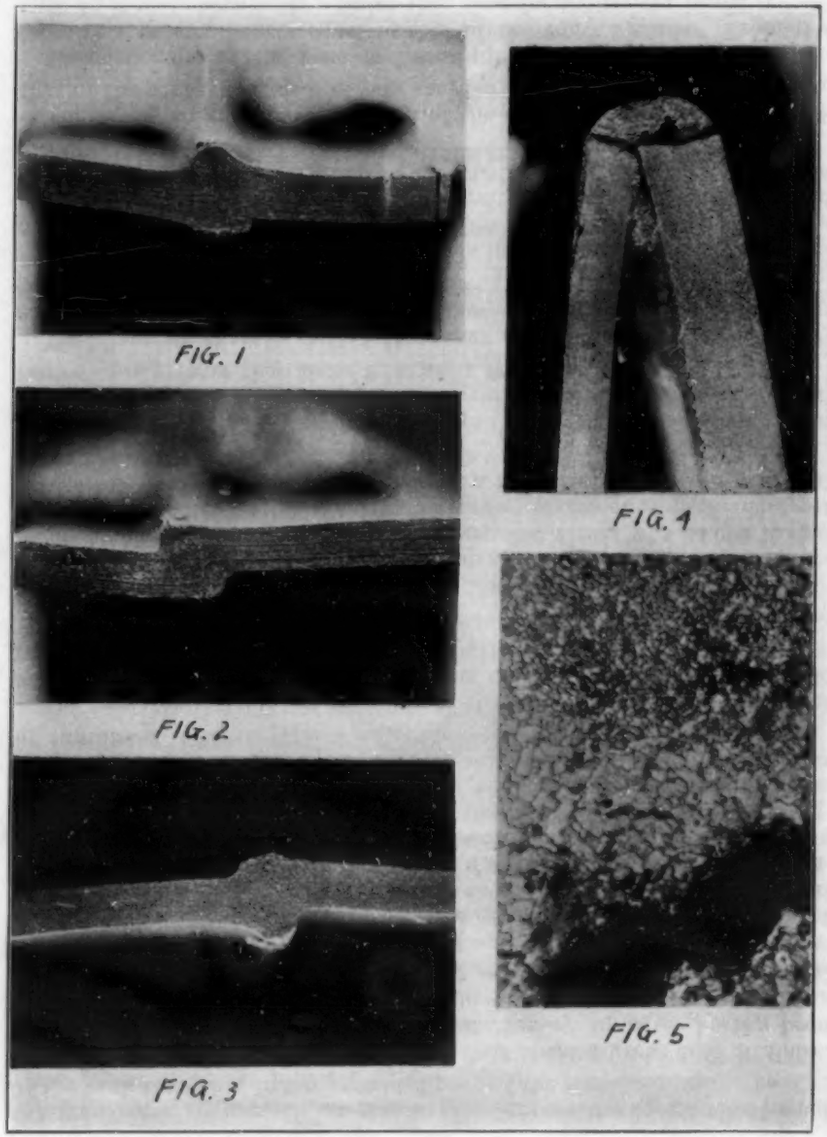

FIG. 1

FIG. 4

FIG. 2

FIG. 5

FIG. 3

grain size was retained by the rapid cooling to which it was subjected.

*Metallurgical Department, Lehigh University.

Fig. 1 *Deep etched* *Magnified* 3 *diameters*

Longitudinal weld of tank No. 1.

The direction of the rolling of the sheet used in the manufacture of the tanks was parallel to the cross-section of the tank. Evidence of this fact is confirmed by the above macrograph. The small striations shown are flow lines which emphasize the direction of the rolling. As the welded area is approached the flow lines seem to come to an end. By close examination of the weld it would seem that there are a few small gas holes present. The entire area is about what would be expected of the section of metal with the same treatment and prophesies good properties.

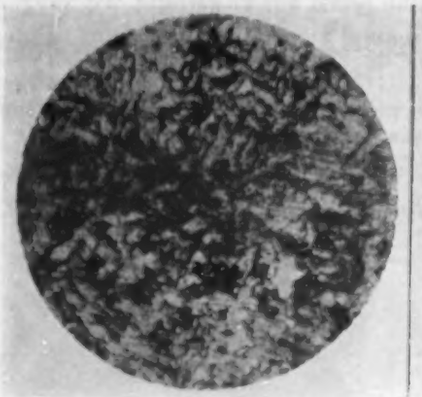

Fig. 6

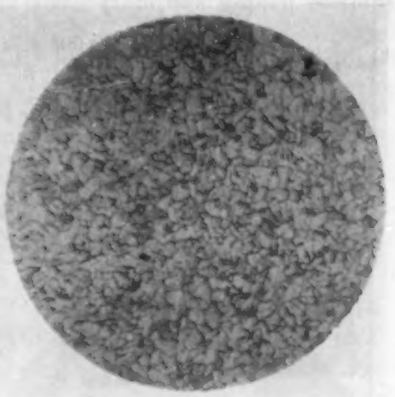

Fig. 7

Fig. 2 *Deep etched* *Magnified* 3 *diameters*

Longitudinal weld of tank No. 4.

The deductions drawn from this macrograph are similar to those deduced from Fig. 1. It would seem as if some of the flow lines on one side of the weld turn to meet and join some flow lines from the other side of the weld, but this is in all probabilities a chance meeting and means nothing to the structure.

Fig. 3 *Deep etched* *Magnified* 3 *diameters*

Longitudinal weld of tank No. 5.

This macrograph reveals a very uniform structure throughout the metal and freedom from gas holes.

Fig. 4 *Deep etched* *Magnified* 3 *diameters*

Transverse weld of tank No. 4.

The above photograph shows a very deep shadow between the weld and the normal metal which must not be misjudged as a defect. The only defect present is the gas hole or holes which are seen in the

center of the weld. The gas hole was large. The flow lines of the rolling will no longer be seen in the metal since this section is at 90 deg. with the direction of rolling.

Fig. 5 10 *per cent Nital* *Magnified* 100 *diameters*

Transverse weld of tank No. 4. A section taken from Fig. 4 at a high magnification.

This micrograph shows a very distinct junction of the weld. The junction occurs where the fine grains and coarse grains meet. The

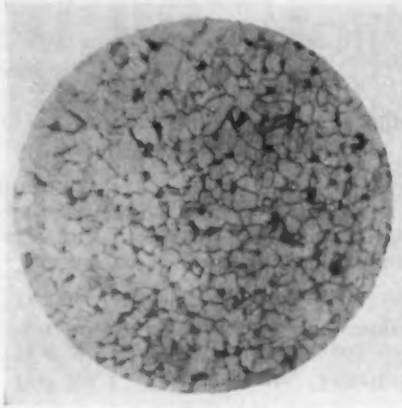

Fig. 8

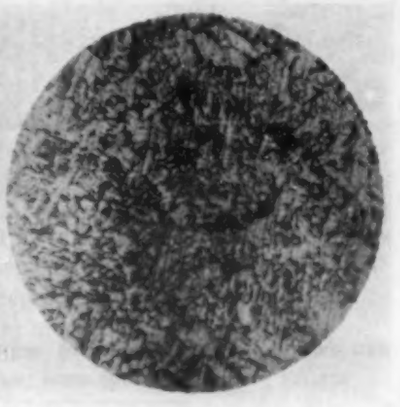

Fig. 9

fine grained area is intermediate between the weld (the large crystals shown) and the normal metal. The size of the fine grains is determined by the temperature to which they are heated and by the speed of their cooling. Fine grain size does not in itself weaken the metal. The black area represents a small section through gas holes in the weld.

Fig. 6 10 *per cent Nital* *Magnified* 100 *diameters*

Weld metal in longitudinal weld of tank No. 4.

This photograph reveals the microstructure of the welded metal itself. The structure is coarse, which is due to the temperature to which the metal was heated and also to the slow cooling of the metal after the weld. There has been little scientific work done upon the microstructure of butt welds and it would be difficult to say that this structure is typical of a butt weld. It is, however, quite typical of the welded metal which was examined during these tests. The metal in the longitudinal welds of the tanks was in every case more resistant to failure than some other portion of the tank. This does not necessarily mean that the welded metal is stronger than the normal metal, because in each case there is an increased cross-sectional area where the weld exists. The structure of this welded metal must, however, have been safe and proper for its particular use since it did not fail in test.

Fig. 7 10 *per cent Nital* *Magnified* 100 *diameters*

Metal intermediate between welded metal and normal metal in longitudinal weld of tank No. 4.

This metal was heated enough by the welding temperature to refine the grain size of the metal (normal) and was cooled sufficiently rapidly by the cold adjacent metal to retain this small grain size. The junction of the weld was not noticeable in this weld.

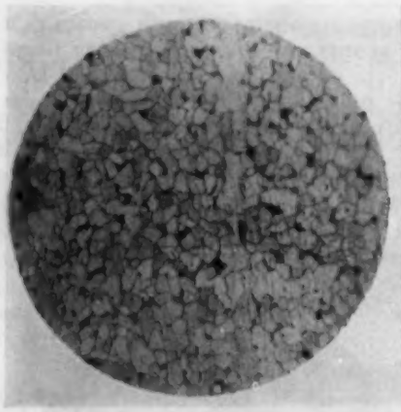

FIG. 10

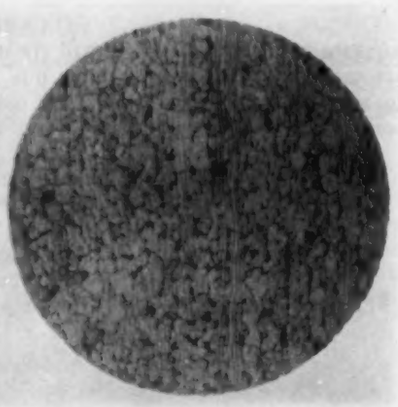

FIG. 11

Fig. 8 10 *per cent Nital* *Magnified* 100 *diameters*

Normal metal of tank No. 4.

This micrograph reveals the structure of the boiler plate after rolling and is characteristic of metal of this type. It was taken adjacent to Fig. 7.

Fig. 9 10 *per cent Nital* *Magnified* 100 *diameters*

Tank No. 1 failed in the metal quite apart from any welded section, and it was deemed advisable to examine the metal near the failed section. This micrograph shows a section of the welded metal in tank No. 1. There does not exist any condition other than is shown under Fig. 6.

Fig. 10 10 *per cent Nital* *Magnified* 100 *diameters*

A section of the normal metal in tank No. 1.

This structure is very similar to that of Fig. 8. However, it reveals traces of interdentritic segregation which is manifested by the white streaks in the micrograph. These white streaks are segregation of pure iron with no carbon content. This pure iron (ferrite) is weak in comparison with the remainder of the metal. Whether this inter-

dendritic segregation caused the failure of the metal is difficult to predict without further examination. It is undesirable in good steel, even though it might not be particularly dangerous in the amount that is present in this specimen.

Fig. 11 10 *per cent Nital* *Magnified* 100 *diameters*

A section of metal near section of failure in tank No. 1.

This structure shows the continuation of the interdendritic segregation in the metal near the failure. The grain size is distorted due to the stretching of the metal just before rupture.

Pulsation Test on Longitudinal Seam Electric Resistance Compression Butt Weld

(From information supplied by the John Wood Manufacturing Co.)

Test No.	Size of Tank	Gauge Hd.	Gauge Bot.	Gauge Shell	Total Hrs.	Total Pulsations
1	12″ x 48″	9	9	.101	272½	212,940+
2	12″ x 48″	9	9	.101	396	308,880+
3	12″ x 48″	9	9	.101	393	306,540+
4	12″ x 48″	9	9	.125	118 hrs. 40 min.	92,560+

Test No. 1. Test continues. Longitudinal seam shows no sign of failure.

Test Nos. 2 and 3. Discontinued to allow for special test on chrome and copper tanks. Longitudinal seam intact at discontinuation of test.

Test No. 4. Test continues. Longitudinal seam shows no sign of failure.

The above test was conducted by connecting the tanks to a 150-lb. per square inch service line through a quick acting valve which was operated by means of a motor giving thirteen (13) pulsations per minute.

By using the quick acting valve the pressure, varying from 150 lb. to 160 lb. per square inch, was applied suddenly.

(Signed) Marland, Supt.

(Signed) A. T. Snow

Outline of Welding Processes

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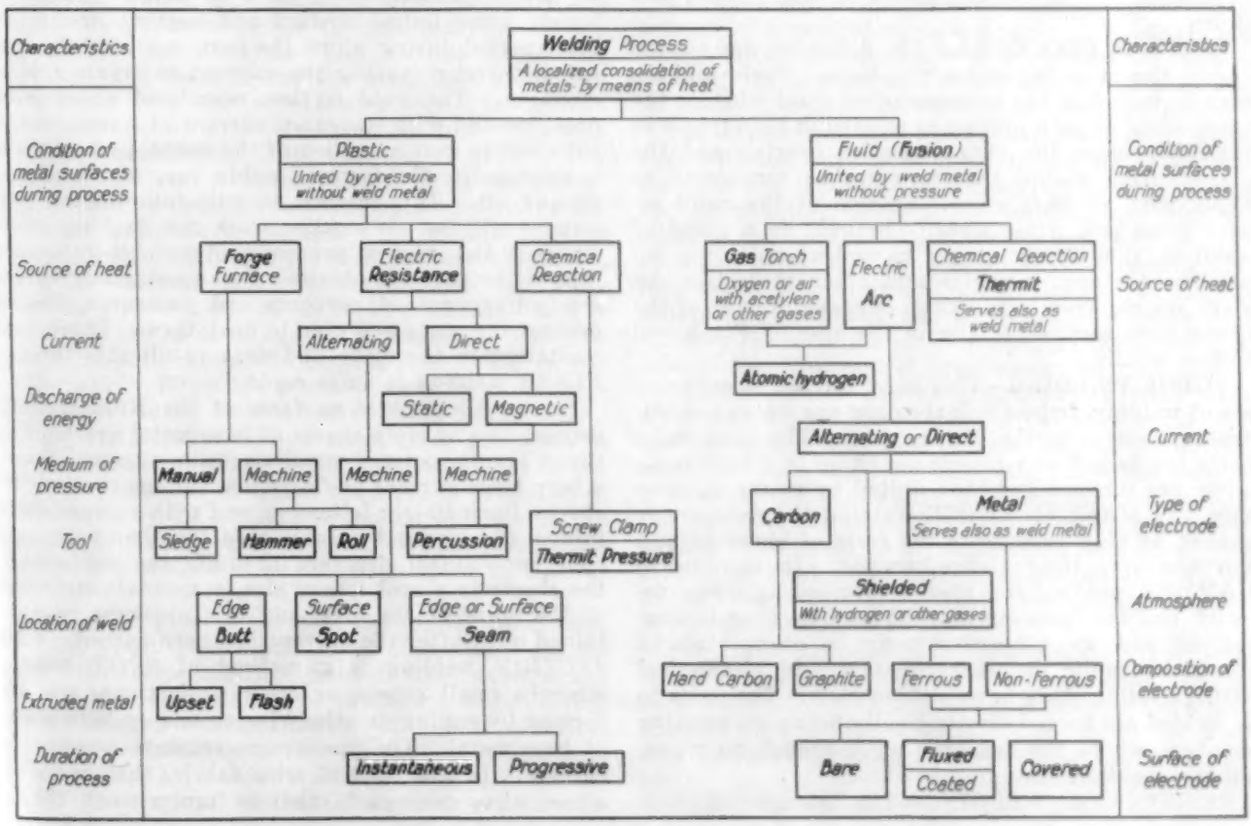
✦ This article was prepared at the request of the Recommended Practice Committee of the American Society for Steel Treating with a view to its publication in National Metals Handbook. It has been published in "Metal Progress." The author is indebted for valuable suggestions to the following men who kindly read a first draft of the manuscript but are not responsible for the article as published:—A. M. Candy, General Engineer, Westinghouse Electric and Mfg. Co.; J. H. Deppeler, Chief Engineer, Metal and Thermit Corporation; H. H. Moss, Engineer, The Linde Air Products Company; H. A. Woofter, Chief Engineer, Swift Electric Welder Co.

SCOPE—This article gives an outline of welding and its allied processes as they exist today (July, 1930). Special attention is paid to the characteristics and inter-relation of the newer processes. Description of the processes is supplemented by notes on the effect of heat treatment, methods of testing, physical properties and fields of use. Gas-cutting methods are included. Questions of cost and matters of patent are not discussed. The attempt to classify the processes and their uses from the standpoint of function is believed to be original with the author. In other respects the information presented is drawn from various sources, notably the publications of the American Welding Society.

DEFINITION—Welding may be briefly defined as a localized consolidation of metals by means of heat. While it is true that, as a laboratory experiment, the surfaces of certain metals can be united without heat, and that the several welding processes involve other factors in addition to heat, yet the importance of heat in all practical welding operations warrants its inclusion as a controlling factor in any useful definition. The welding processes proper are usually employed to unite like metals for the purpose of transmitting considerable stress. The definition includes subsidiary processes, such as BRAZING and SOLDERING, in which unlike metals are employed, and whose product is not usually intended to transmit much stress. These subsidiary processes will not be described in further detail here.

SURFACES—It is both logical and convenient to consider the condition of the metal surfaces in the locality of the weld during the operation of welding as the first criterion in the classification of welding processes. The predominant condition of the metal at, and adjacent to, the surface may be either plastic or fluid. If plastic, the application of external pressure is necessary, but no added material (weld metal) is required. As a result of pressure the parts to be welded (base metal) are reduced in length, width or thickness. If the surfaces are in fluid condition the addition of weld metal is necessary, but no pressure is required. As a result of the added material the base metal parts are usually enlarged either in length, width or thickness.

CHART CLASSIFYING THE PRINCIPAL WELDING PROCESSES



The term FUSION is popularly applied to those welding processes in which the surfaces are in fluid condition. The fluidity is essentially liquid in nature but there are indications of a partially gaseous state in the weld metal during some processes.

In both the plastic and the fusion processes the surfaces to be welded must be free from foreign matter, but the presence of ordinary mill scale is usually not harmful and in certain electric RESISTANCE processes it is advantageous. In all plastic processes the surfaces are brought into close contact, whereas in most of the FUSION processes the provision of a narrow space between surfaces has the beneficial effect of relieving internal cooling stresses and also of permitting a more efficient weld.

The plastic zone of most metals ranges from melting point down to about 100 deg. (F.) below melting. In a few metals, such as lead and cast iron, the zone is so narrow that they are difficult to weld except by fusion. In the case of many metals (copper, brass, bronze, aluminum) oxidation begins at the temperatures needed to prepare the work, and the welding operation must therefore be either instantaneous or shielded.

SOURCE OF HEAT—In the plastic processes heat is produced either by a FORGE furnace, by RESISTANCE at the base metal surfaces to electric current, or by a progressive chemical reaction (THERMIT). Strictly speaking, the combustion of fuel incident to FORGE and GAS processes is a chemical reaction, but it is convenient here to confine the term to special reactions such as accompany a THERMIT process.

In the FUSION processes heat is produced either by the combustion of gases mixed in a GAS torch, by an electric ARC, or by a THERMIT chemical reaction. In many FUSION processes a temperature several thousand degrees (F.) higher than the melting point of steel occurs at certain points in the heating medium.

SPECIFIC PROCESSES—The following description covers the more important processes. Their relation may be traced on the accompanying chart wherein the trade-name of each process is printed in bold type. In some processes the characteristics overlap and the classification should therefore not be considered to apply with absolute rigor. Several of the more recent processes, while already brought to a point of commercial utility, must be viewed as still in a development stage. Goggles and other protective devices are required by workmen engaged in most of the newer processes, especially in the case of Flash and Fusion welding.

FORGE WELDING—This is by far the oldest process of welding, indeed it is the only one whose general practice antedates the 20th century. The base metal parts are heated to a plastic condition in a coal, coke, oil or gas furnace and then united by means of pressure. In MANUAL FORGE welding the pressure is applied at high velocity in the form of blows from a comparatively light sledge-hammer. In mechanical HAMMER welding the blow is applied at lower velocity but the hammer may be as heavy as is convenient and its momentum may be augmented by steam, hydraulic or other pressure. In mechanical ROLL welding there is no sudden blow. The parts to be welded are forced longitudinally betweeen rotating members whose bearings are rigid enough to transmit the required pressure.

RESISTANCE WELDING—The electric RESISTANCE processes originated with an accidental discovery by Elihu Thompson in 1885. These processes require the localization of heavy current combined with great mechanical pressure. Alternating current is usually employed except on very small work. With equipment of the efficiency available at the present time the current and compression requirements (per square inch of area to be united) for the RESISTANCE welding of medium rolled steel are, respectively, 30 kva. for 10 seconds and not less than 5000 nor more than 8000 lb. The electric power required for other durations varies inversely as the time. The mechanical pressure required does not vary with the time, but it must be modified for different grades of base metal.

An important feature in all RESISTANCE processes is the composition of the electrode DIE which must possess good thermal and electric conductivity combined with great hardness and sufficient strength. A combination of these requirements has been achieved to a high degree by the use of a hard copper electrode faced with one of several alloys whose hardness at the welding temperature of the product is much greater than that of copper.

In the BUTT welding form of the RESISTANCE process pieces of the same cross-section are mechanically gripped and pressed together while heat is generated by passing a very large electric current through the area of contact. The original UPSET method is a form of BUTT welding in which high mechanical pressure is applied and maintained throughout the operation, the temperature being kept below melting. The extruded metal is upset into a roughly convex form which, if desired, may be molded to predetermined shape in a die, thus securing a kind of drop-forging, or it may be ground off. Today the UPSET method is generally combined with flashing. The FLASH method as first developed, is a form of BUTT welding in which, after initial contact and heating, there is a brief period during which the parts are slightly separated, thereby causing the current to create intense sparking. The weld is then completed under great pressure and with increased current at a temperature sufficient to melt a portion of the metal, part of which is extruded in the form of a thin burr which may be ground off. This method is still followed on very large work, but on smaller work the flashing effect, which in the original process was secured by separation of the parts, is obtained by an automatic successive adjustment of currents and pressures, first to preheat the parts and then to flash them. There is no hesitation in the cycle and as a result this form of FLASH welding is quite rapid.

In the SPOT welding form of the RESISTANCE process two or more sheets of base metal are held between bluntly pointed metal electrode dies which pass a very large current at fairly low voltage through the sheets. Immediately following, and with current maintained, the electrodes are forced together with sufficient mechanical pressure to unite the surfaces of the sheets in a spot whose size is approximately that of the point of the dies, and this pressure is maintained until after the current has been cut off. PROJECTION welding is a method of SPOT welding wherein small ridges, or other projections, are preformed by rolling or otherwise on one or both pieces of base metal. The projections serve to localize the current. In the case of wire fabric, that is to say where wires cross each other to form a mesh, the de-

sired localization is provided naturally from the contour of the wires.

The SEAM welding form of the RESISTANCE process involves features allied to both BUTT and SPOT welding. Two or more sheets or bars of base metal are passed between electrode-rollers, or between a succession of dies, which transmit the current and the mechanical pressure required to produce a welded seam, usually as a series of closely welded stitches. An important recent process for welding the longitudinal seams of steel tubing utilizes direct current by means of a homo-polar generator.

ELECTRO-PERCUSSIVE WELDING—The PERCUSSIVE methods of RESISTANCE welding differ from BUTT or SPOT welding in that (1) a direct current supply is essential, (2) there is a sudden discharge of electrical energy at the junction in an arc which is extinguished by a percussive blow, and (3) the surfaces united are partially fluid. The energy may either be supplied by the discharge of a condenser (electrostatic), or transformed by the collapse of a magnetic field (electro-magnetic).

THERMIT PRESSURE WELDING—The THERMIT PRESSURE process has also been called Thermit Pipe Welding for the reason that at one time its largest use was to connect the ends of pipe, but it is now also employed in other important fields. The chemical reaction which generates the required heat will be described in connection with the THERMIT process proper in which the thermit acts both as heating and filling medium, whereas in the THERMIT PRESSURE process it serves merely to generate heat.

In applying the process to pipe the pipe ends are cut square and faced, any threaded portions being removed, and they are then butted together by means of clamps actuated by longitudinal bolts. Light cast iron mold segments are placed so as to form a space around the butted pipe ends and into this space are poured the products of the thermit reaction, molten iron and molten alumina. The alumina enters the mold first and coats it and the pipe, thus protecting these parts from the superheated iron. In a short time these molten products bring the pipe ends to a welding temperature. This time varies from a few seconds to several minutes, depending on the size of pipe. Welding pressure is then applied by giving the bolts one complete revolution. The clamps may be released immediately and the mold segments removed, when the thermit iron and the alumina fall away from the pipe and out of the mold segments, thereby permitting the mold to be used repeatedly. The pipe joint is slightly upset, its enlargement being on the outside only. When the process is employed on coils the pipe is usually welded before being bent.

GAS WELDING—We now leave those processes in which external pressure is employed and come to the FUSION processes in which the weld is produced in a fluid state by the addition of molten weld metal. In continental Europe the term AUTOGENOUS is applied to any method of so doing by means of GAS or ARC.

In the GAS process the heat is supplied by a flame resulting from the combustion of compressed oxygen or air with compressed acetylene or other gases mixed in a torch so regulated as to produce a flame having certain desired characteristics. The first practical oxy-acetylene welding torch was devised in Paris in the year 1901 by Fouché and Picard. The construction of the various torches of commerce differs in detail, but in all designs the two gases are supplied through separate passages, their pressures are regulated independently, and they are thoroughly mixed prior to combustion. After mixing, the gases are forced through a torch-tip, of size suited to the work in hand, at whose orifice combustion takes place in the form of an incandescent cone. If the mixture contains an excess of acetylene a carburizing flame results. If an excess of oxygen, an oxidizing flame results. If acetylene and oxygen are balanced, a neutral flame results. In almost all GAS welding operations the maintenance of a neutral flame is required, but in the welding of certain alloys such as aluminum a slightly carburizing flame is permissible. In some methods of welding aluminum hydrogen is advantageously substituted for acetylene. An oxidizing flame must always be avoided.

The weld metal is usually supplied independently in the form of single pieces of welding rod whose size, composition and coating (FLUX), if any, vary with the work to be done. In the union of thin sheets the weld metal may be taken from surplus base metal.

In manual GAS welding the operator holds the torch in one hand so that the tip of the incandescent cone almost touches the base metal, while with the other hand he maintains the end of the welding rod near to the work. He oscillates the flame over the base metal, first slightly ahead of and then at the weld, so as to melt it into a puddle. The rod is melted solely by heat radiated from the flame and puddle, and in melting it adds to the volume of the puddle. When the molten metal deposited in the puddle attains sufficient volume both flame and rod are moved progressively forward (or backward) thus permitting the deposit to solidify and cool gradually as an integral portion of the base metal parts.

Machines that are automatic except as to the maintenance of a neutral flame are being increasingly employed in GAS welding, but as yet industrial applications of the process are mostly manual. Welds may be made in either flat, vertical or overhead position.

The shape and size of the deposited weld metal vary with the work to be done. In making butt joints, which are a type to which the GAS process is preeminently suited, prior to the welding operation the edges of the base metal are usually bevelled, a narrow shoulder being left square, so that after assembly they take the form of a single or double Vee slightly separated at the root, and the space thus provided is filled by the weld metal. For most purposes the open side of the Vee, and if practicable the root also, is reinforced by the convex protrusion of weld metal somewhat beyond the surface of the base metal. The GAS process is also used to make lap and other types of joint. In a lap joint the weld takes the form of a triangle (fillet) whose cross-section lies outside the planes of the base metal and whose hypotenuse is usually reinforced. In all GAS welds the entire cross-section of weld metal may be deposited at one time, in the case of very thick welds the deposit being laid in sloping formation.

For many purposes the base metal is preheated before being GAS welded. The preheating may be done with a torch in which gases cheaper than compressed oxygen and acetylene are used, the work may be surrounded by a charcoal fire, or it may be placed in a furnace. Preheating has several advantages. It reduces any tendency of the welding

operation to cause subsequent cooling strains. It decreases the consumption of the more expensive gases, oxygen and acetylene, and when done in a furnace it saves the operator's time. It also improves the quality of the joint by releasing such internal stresses as may already exist in the base metal. The duration of the GAS process causes the heat generated at the weld to extend back over a considerable area, and this makes preheating very desirable in the welding of materials having low ductility.

GAS CUTTING—While the process of cutting ferrous metals by means of a gas flame is foreign in function to that of welding, it is included here because it is performed with the aid of a torch whose construction, fuel and operation are very similar to those employed in welding. There are differences, however.

The CUTTING torch is provided with an additional third passage for the transmission of oxygen under high pressure, for it is the chemical combination of oxygen with the metal, and not the heat of the flame, that does the cutting. Moreover, while in GAS WELDING practically the only gases used are oxygen and acetylene, in GAS CUTTING the acetylene may be replaced by a cheaper fuel such as hydrogen or hydrocarbon gases.

In the CUTTING process a small spot of the metal to be cut is first heated to a red temperature under a neutral flame. The high-pressure oxygen valve is then opened and this causes a jet of almost pure oxygen to impinge on the glowing metal. The result is a chemical combination of iron and oxygen to form iron oxide, thus creating a depression that soon becomes a slit (kerf) in the metal. The pressure of the oxygen blows the oxide away as fast as it is formed.

The popular use of the term "burning" as applied to this process is not quite correct, for only the oxide removed is burned. The remaining edges of the base metal are tempered to a depth that seldom exceeds ⅛ inch.

For greatest efficiency the oxygen pressure and the angle at which the jet should be aligned vary with the thickness and grade of the metal to be cut. Makers of gas-cutting equipment have prepared charts giving the result of different combinations of pressure and angle. Steel containing a high percentage of carbon should be preheated prior to cutting.

The cutting of cast iron requires a sidewise oscillatory motion of the jet, and certain flame adjustments. In the cutting of fabricated parts that will later be subjected to major stress, as in the case of structural and machine steel parts, sidewise oscillation should be avoided. Any irregularity results in notches which may soon develop into cracks. Regularity of motion and smooth cuts may be secured by the use of an automatic cutting machine, or by the employment of a template along whose edge the torch tip is guided. Tests indicate that steel parts that have been smoothly cut by this process are stronger than if sheared, and almost as strong as if machined.

The largest steel ingots or other similar objects can be rough-sheared by the combination of a cutting torch and an OXYGEN LANCE. The lance is a simple device that may also be used alone for piercing large ferrous masses. It consists essentially of a nozzle composed of a suitable length of ⅛ or ¼ inch steel pipe connected by means of strong hose to a supply of compressed oxygen. For reasons of safety and economy certain accessories are desirable. A manifold regulator maintains the volume of oxygen at a moderate pressure. Woven hose with no wire winding should be employed, and care should be taken that it has not been used for other purposes on account of dangerous greases that may remain. A 3-foot length of one inch extra strong bent pipe, inserted between the nozzle pipe and the hose, serves as a handle. In operating the LANCE a spot on the mass to be pierced is made red-hot by any convenient means and on this spot is switched an excess of oxygen which, by combining with the iron, rapidly bores through the mass. The end of the nozzle pipe is consumed as the hole deepens.

ARC WELDING—The discovery of the practical possibilities of the electric ARC process of FUSION welding arose from the fortuitous fact that in the process of wire drawing enough lubricant remains on the wire to furnish the flux needed to make a weld. The industrial development of the ARC process originated during the World War. There are many methods of applying the process which differ in detail, but in all of them an arc is struck between an electrode and the parts to be welded, thereby generating intense heat which fuses the parts with the weld metal used.

Alternating current is employed to some extent, notably in erection work where the greater portability of its light transformer equipment is advantageous, but for most other purposes it has been found preferable to use direct current despite the greater weight of its motor-generator equipment. Generators may be of constant potential, constant energy or constant current type. When thick medium steel is to be welded by direct current the base metal usually serves as the positive pole, the electrode forming the negative pole. This is for the reason that greater heat is generated at the positive pole. If the base metal is thin or of a high carbon or alloy grade the polarity is generally reversed.

ARC welding may be performed either manually or by automatic machines having one or more heads. In full-automatic machines both travel and feed are controlled mechanically. In semi-automatic machines only the feed is controlled mechanically. Manual welds may be made in any position.

In the CARBON ARC process the electrode is composed of carbon. It is utilized only to produce heat, the weld metal being either taken from surplus base metal or supplied independently by a welding rod manipulated similarly to that used in GAS welding.

In the METAL ARC process, which is the more prevalent at the present time, the electrode is composed of a suitable grade of metal which serves as one pole of the circuit and at the same time provides weld metal by the progressive melting of its end. In manual operation the electrode is manipulated by means of a holder, the use of only one hand being required.

The weld metal, whether supplied independently or by the electrode, is commonly furnished in the form of wire of substantially the same grade as that of the parts to be welded. In manual ARC welding common diameters of wire are 5/32 and 3/16 inch. These sizes require about 160 and 200 amperes of current respectively, the voltage being about 20 in both cases. If automatic machines are employed it is feasible to use larger diameters, higher currents, and consequently greater speed. ARC welds having a depth of not over ⅜ inch are usually made in one layer. If

½ inch in size, two layers are common practice. If ¾ inch or over, three or more layers are used. If the joint is of a rigid type it is advantageous to lightly hammer (peen) the inner layers. The weld may be of butt or lap type and of any desired form. The ARC process is adapted to making a fillet weld of any size.

There are several special processes of ARC welding which permit the use of larger diameters of welding rod, higher current and greater speed than are feasible when BARE wire is used in conjunction with the ordinary process. These special processes also aim to produce a weld having increased ductility. In one such process both electrode and deposited metal are SHIELDED from oxidation by the maintenance of an atmosphere of hydrogen, water gas, alcohol vapor or other reducing medium around the arc. In the ELECTRONIC TORNADO process similar shielding is provided, together with the superimposing of a strong magnetic field on a carbon arc which, while appearing to give it a gyratory motion, permits the arc to function without essential disturbance. In another recent process a bare metal electrode plows with oscillating motion through a thick mass of fluxing material which serves both as a shield for the arc and as a blanket to permit the metal already deposited to cool slowly. These special processes are usually applied by means of automatic machines which operate to greatest advantage on flat work.

In conjunction with both ordinary and special processes of ARC welding the wire may be coated with either a slagging or a fluxing medium which cooperates in permitting the use of larger welding rods, higher current, greater speed, and usually increased ductility. Such wire is said to be FLUXED. A FLUXED type of wire is essential if alternating current be used. If enveloped by a fabric which either serves to retain the flux or which has itself been impregnated with a suitable flux or alloy, the wire is said to be COVERED.

The ATOMIC HYDROGEN method of welding embraces features of both GAS and ARC processes. While an ARC is the initial source of heat, the base metal forms no part of the electric circuit but is fused by heat from a so-called flame as in the GAS process. In the ATOMIC HYDROGEN method a fine jet of hydrogen is forced through an alternating arc formed between two tungsten electrodes. The high temperature of the arc momentarily breaks down the hydrogen molecules into atoms which, after passing through the arc, recombine into molecules and in so doing give up the heat absorbed during dissociation. The result is a flame of hydrogen whose temperature is higher than that of any other known flame. The weld metal is usually supplied independently as in the GAS process, but for some purposes it is taken from surplus base metal. The magnitude of the current is limited by the combustibility of the tungsten electrodes, and hence the process is largely employed on thin materials. In the union of such materials as suit the process, a quality of weld results that is both sound and smooth. Alloys, such as high chromium and high nickel steels, are readily welded by this process.

THERMIT WELDING.—The THERMIT FUSION process, commonly known as THERMIT welding proper, originated with a discovery made in Germany, about 1900, by Dr. Hans Goldschmidt. He found that if a mixture of metallic oxide and finally divided aluminum were ignited at one spot, the two materials would react exothermically and liberate much heat, and the reaction would progress throughout the mixture, thereby converting it into two new materials, a superheated mass of the metal itself and a slag composed of molten aluminum oxide (alumina). He further found the reaction would progress so rapidly that in the case of most metals a ton of material could be converted from a cold mixture in half a minute. Later, the most suitable kind of iron oxide (Fe_2O_3), the best size of its flakes, and the proper percentage of its fines for use in welding steel were developed, as well as the possibilities resulting from the addition of such elements as chromium, nickel, vanadium, manganese, to a THERMIT STEEL mixture.

In the THERMIT process as practised today the parts to be united are separated by a space whose extent depends on their size, and their surfaces are thoroughly cleaned by sand-blast or otherwise. Usually this space is given the form of a parallel-sided gap cut by means of a gas torch, the slight layer of oxide resulting from the cutting process being apparently beneficial. Around the parts a wax pattern is formed whose shape is that of the reinforcement desired. A sheet iron box is placed around this pattern with a space between it and the pattern, and when the wax has hardened sand is rammed into the space, provision being made for a proper number of risers and pouring and heating gates. Then the wax is melted by directing a flame of compressed air and liquid fuel into each heating gate, and as it flows away it leaves clear the space to be occupied later by the THERMIT STEEL. Heat is continued so as to dry out the sand mold and to bring the parts to be united to a red temperature. If multiple sections are to be welded, a two-part mold and a special wooden pattern may be substituted for the box and the wax.

Meanwhile a proper THERMIT mixture has been placed in a crucible supported over a pouring gate or gates, and when the work is ready it is ignited. In about half a minute the reaction is complete and the THERMIT STEEL is then tapped from the bottom of the crucible into the pouring gate. The superheated metal flows around and between the parts to be united, thoroughly fusing with their surfaces and welding them into one homogeneous mass, while the molten alumina slag overflows into a basin on top of the mold.

HEAT TREATMENT.—Many products that have been welded by the several processes described are used for purposes requiring subsequent heat treatment. Results indicate that the fused metal is certainly not injured by such treatment, although further investigation is needed to determine the extent to which it is improved. Probably the grade of weld metal used in FUSION welding has an important effect on the results of subsequent heat treatment. The indications are that annealing does not change the grain structure of ordinary weld metal to any appreciable extent, and that its influence on alloy weld metal, while greater than in the case of the commoner grades, does not result in more than 12 to 15 per cent increase in ductility. Annealing is applied with substantial benefit, however, to a number of welded objects for the purpose of relieving unequal cooling stresses.

TESTING.—Welded specimens may be tested by destructive methods in the same manner as are base metal specimens, but their yield point and ductility are not readily determinable by these means. In the

case of FUSION products the fact that the yield point of the weld metal is frequently higher than that of the base metal united tends to cause necking in the adjacent base metal before the weld metal is fully stretched. Yield point and ductility can be ascertained by testing specimens of virgin weld metal, but such tests do not necessarily reflect the character of the welded assembly. Several forms of bend test have been developed with a view to confining the part measured to the weld metal, and there are grounds for expecting that acceptable standards for so doing will be established in the near future.

The soundness of a weld may be determined non-destructively in various ways. For laboratory use, electrical, magnetic, and X-ray methods are employed. In the electrical method the variation in resistance to passage of current is used to detect the location and magnitude of a defect within the weld. In one magnetic method an oscillograph records any difference in the composition of the specimen being tested as compared with that of another specimen whose quality has already been determined.

For shop and field use, the nature and regularity of the crackling sound produced by a welding arc have been found to reflect the uniformity of a weld, and in all fusion processes visual inspection of the exterior of the weld has real value as an indication of its integrity. The interior of a weld may be explored by means of a gas torch, the portion thus melted being subsequently re-welded. A stethoscope may be employed to detect by means of sound the location and extent of any non-homogeneous portion of the weld. Much emphasis is placed on the assurance of weld quality securable by the periodical qualification of operators wherein they are called upon to weld specimens which must develop predetermined unit strength when tested to destruction. Proof tests may be applied to the finished work by observing its behavior when subjected to a load of 1½ to 2 times that for which it was designed.

PHYSICAL PROPERTIES.—The strength and ductility of objects welded by the older FORGE processes are adequate for the minor uses to which such products are usually put, but these uses do not include joints having high predetermined efficiency. No unit basis has been suggested for rating the physical properties of FORGE welds.

In all RESISTANCE welding processes the efficiency of a joint depends primarily on the suitability and the adjustment of the machine employed for each specific purpose. If the electric power is too high, or its duration too long, the metal will be overheated. If the mechanical pressure is too high the length or the cross-section of the welded material will be excessively reduced. If either of these factors is too low no union will result. With an adequate machine that is kept in proper adjustment any RESISTANCE process produces a weld whose strength and ductility are substantially equal to those of the parts united.

In the determination of physical properties the RESISTANCE differ from most of the FUSION processes. The efficiency of an individual type of joint welded by a RESISTANCE method duplicates what has been found to result from the employment of an automatic machine specially designed to suit that type of joint considered as a whole, whereas in FUSION welding the efficiency of a joint in terms of some unit of its area, is predicated on tests that have been made on similar, but not necessarily duplicate, joints made by a similar method, but not necessarily with the same equipment. In both processes qualification tests should be applied, in the case of RESISTANCE welding to the machine, in the case of FUSION welding to the operator.

The strength of welds made by either the GAS or the ARC FUSION process may reach almost any desired amount, depending on the details of the process and on the grade of weld metal used. If the rod is a suitable grade of soft or medium steel, the tensile and shear properties of the welded joint, in pounds per square inch, may be conservatively expected to average approximately as follows:

Ultimate Tensile Strength	50,000
Tensile Yield Point	40,000
Ultimate Shearing Strength	36,000
Tensile Modulus of Elasticity	29,000,000
Shearing Modulus of Elasticity:	
G (American double basis)	10,500,000
E 2 (Metric single basis)	21,000,000

In general the ductility of a GAS weld is higher than that of an ARC weld produced in the ordinary manner with bare filler metal, but the ductility of either may be improved by the several means previously described.

The resistance of FUSION welds to shock and fatigue has not yet been fully determined on a unit basis, but many joints made by these processes have been subjected in industrial service to severe impact, over long periods of time, without showing sign of distress. Experience indicates that a weld whose length is parallel to the direction of stress will resist shock better than one disposed transversely.

The tensile strength of an unworked and unheat-treated THERMIT weld, using an ordinary mixture of thermit metal, may be placed at about 70,000 lbs. per sq. in. with an elongation in 2 inches of 20 to 25 per cent. By suitably varying the composition of the mixture welds having lower strength and higher ductility, or vice versa, as well as great resistance to wear, are securable. THERMIT welds stand up very satisfactorily under drop test.

FIELDS OF USE.—Two basic methods other than welding have long been employed to unite metal parts for the purpose of transmitting stress. One is a mechanical operation in which a portion of each part is first removed, in the form of round holes, slots, threads or other openings, and the removal metal is then replaced by INTERLOCKING pieces usually in the form of rivets, bolts, nuts or keys. The other method depends on surface FRICTION between the parts, the friction being produced by mechanical pressure while the parts are cold or by the thermal shrinking of one part after it has been heated. Both of these methods reduce the available strength of the parts.

The fields to which the several WELDING processes are applicable are those in which it is desired to avoid the loss in strength incident to the older methods and those requiring the joining of parts of greater or smaller size, more irregular shape or in a more restricted space than is otherwise feasible. In the union of parts subject to fluid pressure the welding process also provides a joint which is tight at all temperatures, and which appears to reduce local corrosion and [in the case of boilers] caustic embrittlement. To a large extent the fields covered by the several welding processes differ but there is some overlapping.

The field of MANUAL FORGE welding is limited to

small objects. Quite large and thick parts can be welded under the HAMMER process. For a long time butt-weld pipe up to about 3-inch diameter, and lap-weld pipe up to about 30-inch diameter have been ROLL welded, while pipe up to 96-inch diameter has been HAMMER welded. These fields are now being invaded by electric RESISTANCE seam welding in the case of the smaller and by FUSION welding in the case of the larger sizes. All processes of FORGE welding as applied to steel require a lower carbon content in the base metal than is necessary under the newer processes.

BUTT methods of RESISTANCE welding are suited to fields where a strong joint is desired. They are applicable to either thick or fairly thin materials. For some years single sections having an area up to 36 sq. in., requiring 900 kva. and a pressure of 100 tons, have been welded by a combination of FLASH and UPSET welding. This limit has recently been surpassed by the welding of solid steel shafting 8½ inches in diameter and of 14-inch steel pipe with 1 5/16 inch wall, the respective cross-sections being 56¾ and 51 square inches. A FLASH method is employed extensively in the joining of tubes and automobile rims and to unite the edges of sheets up to about 3/16 inch in thickness as in the body of automobiles. Material whose edges are not exactly true can be welded by this process.

In theory a SPOT process could be used to unite material of any thickness, but in the case of very thick plates the enormous current and high mechanical pressure required necessitates machinery so heavy as to be impracticable for most purposes. In addition it has appeared necessary to localize the spot area by means of buttons or other devices which so far have not proved commercially feasible. The field of SPOT welding, therefore, has hitherto been largely restricted to thin material, and a similar limitation formerly applied to SEAM welding, but recently improved methods have been developed, notably in the manufacture of pipe, which promise to raise the upper limit of weldable thickness to ½ inch, and perhaps even higher. The PERCUSSIVE processes are especially suited to the multiple welding of different metals or different grades of the same metal as in the manufacture of automobile parts and tools, where it is desired to unite an expensive with a less costly portion. In all processes of RESISTANCE welding, except for very small parts, the weight of the welding machinery requires the work to be carried to the machine, and hence these processes are essentially factory operations. Their employment in quantity production is widespread and, based on value of product, probably three-fourths of all welding being done at the present time is performed by a RESISTANCE process.

While RESISTANCE welding is a rapid, multiple, manufacturing process, FUSION welding may be called rather an engineering tool. The field of FUSION welding embraces all those applications wherein the strength of joints must be pre-designed on some unit basis, as well as a number of miscellaneous uses. In FUSION welding also, except when full automatic machinery is employed, the welding equipment can be taken to the work, thus making the process suitable for both shop and outside installation purposes. Its elimination of noise further broadens the field where FUSION welding may be advantageously used.

The GAS process of FUSION welding is widely used in the production of pressure vessels from the largest sizes down to light drums, the joining of pipe ends and fittings, the manufacture of ferrous-alloy and non-ferrous products, the construction of aircraft, the repair of castings and locomotive parts, and in many other fields where its reliability and convenience make it suitable.

The METAL ARC process of FUSION welding is well established as a production tool for welding the longitudinal seams of the larger sizes of pipe, the fabrication of pressure vessels, and in the construction of machinery bases and other parts. Its employment is rapidly extending in the field of structural steel where its simplified shop fabrication requirements, its possibilities for saving weight in design, and its adaptation to all kinds of reinforcement are frequently important factors. It is used to a considerable extent in ship and barge construction and for many other purposes where speed and economy are desired.

The fields to which the SHIELDED ARC, the ELECTRONIC TORNADO, and the ATOMIC HYDROGEN processes are applicable have been indicated in describing their operation. So far the GAS CUTTING process has been limited to ferrous products.

The THERMIT process proper is used where great strength, ductility and soundness are required in the repair, and at times in the manufacture, of very large objects. It is available wherever a mold can be placed around the parts to be welded. Originally all THERMIT welding was performed by those developing the process, but in later years users have been encouraged to do their own welding. Crucibles and preheating torches are about the only special equipment needed. Mixtures of THERMIT METAL, suitable as to grade and quantity for the purpose desired, together with tables giving all necessary data, are commercially procurable. The process is used extensively for the reclamation of heavy machine parts, marine rudder-frames and propellers, rolling mill equipment, and other important work. It extends to special fields, as in the case of rail joints where rails may be made endless either by the well-known insert method, or the base and web may be welded by a THERMIT FUSION method while the head is welded by a THERMIT PRESSURE method in which the rails are drawn together by means of clamp bolts. A THERMIT PRESSURE method is also used for jointing pipes up to about six inches in diameter.

TECHNIQUE.—As may be inferred from the preceding outline, a definite technique is essential to the securing of the best results in welded objects, this technique differing with the various processes and with the purposes for which the objects are intended. Without the study and adoption of a proper technique disappointment and possible disaster must be expected. By the further development of a suitable technique, which should include the providing of proper jigs and fixtures to hold in place the parts to be united, the newer welding processes promise to extend to fields even broader than those now covered.

Stress Distribution in Welded Steel Pedestals

By JAMES H. EDWARDS, H. L. WHITTEMORE, and A. H. STANG

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I. INTRODUCTION

PEDESTALS are used to support the ends of bridges. They distribute the concentrated load over the top of the masonry or concrete bridge piers. If the lower surface of the pedestal is sufficiently large, the compressive stresses in the pier will be safe.

Bridge pedestals have in the past been either grey iron or steel castings. Cast pedestals have the disadvantages that the patterns are expensive and that the time required to make the castings sometimes delays the completion of the bridge.

Pedestals, especially the smaller sizes, cannot be economically made by riveting together pieces of rolled structural steel. As welding is coming into use for the fabrication of steel structures, the American Bridge Co. designed pedestals of rolled steel plates, joining the pieces by electric arc welding. As the use of welded pedestals was a radical departure from present practice, the cooperation of the bureau was obtained in determining the compressive strength.

II. THE PEDESTALS

Drawings of the pedestals are shown in Figure 1. They were designed to carry a load of 350,000 pounds, and represent one size in a series of pedestals for different bridge spans and loadings.

The difference between the pedestals *F1* and *F2* lies wholly in the connection between the bottom plate and the inclined plates. In pedestal *F1*, the inclined plates (*P2*) do not touch the bottom plate, and the parts of

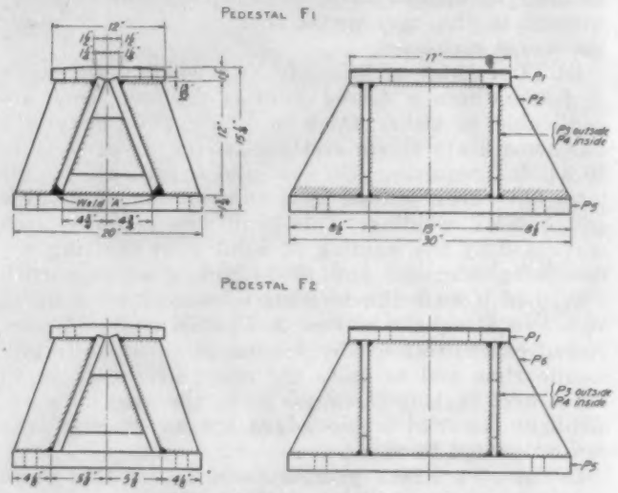

Fig. 1—Drawing of the Pedestals

Material for Pedestal F1

P1, one plate 12 by 1½ by 17 inches.
P2, two plates 12⅛ (finished width) by ⅞ by 30 inches.
P3, four plates 3½ by ⅝ by 12⅛ inches (neat length).
P4, two plates 6 by ⅝ by 8 inches.
P5, one plate 20 by 1¾ by 30 inches.

Material for Pedestal F2

All material same as that in F1 except plates P6 used instead of Plates P2.
P6, two plates 13⅛ (finished width) by ⅞ by 30 inches.

Note.—All welds ⅝ inch except weld A for pedestal F1.

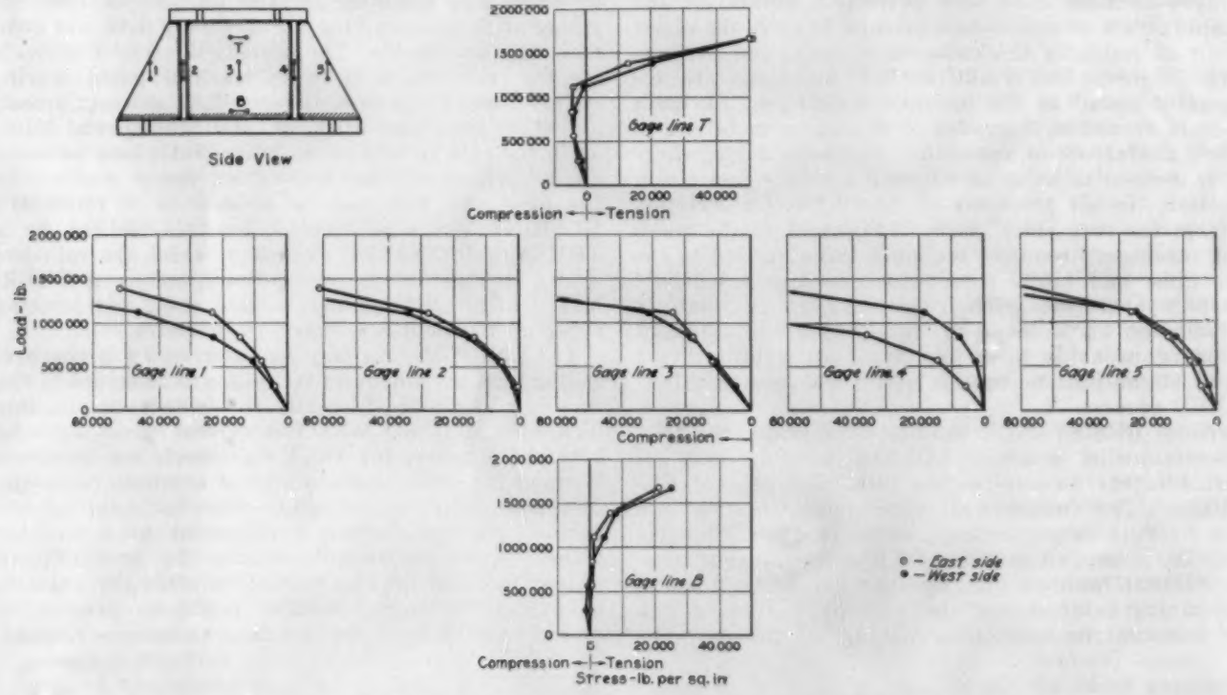

Fig. 2—Stresses in the Inclined Plates and in the Stiffeners of Pedestal F1

the pedestal can be truly lined and clamped in their proper relative positions before the weld "A" is made. The corresponding inclined plates (*P6*) of pedestal *F2* must be carefully finished at both the bottom and the top, and any irregularity in any of the plates may result in uneven bearing after the seams are welded.

III. LOCATION OF STRAIN GAGE LINES

Twenty 2-inch gage lines were used for the study of stress distribution on each pedestal. It was recognized that this number was not sufficient to determine fully the stress distribution, but the results show that much was learned which would aid in perfecting the design. The location of the gage lines is shown in Figures 2, 3, and 4.

It was convenient to designate the four sides of the pedestal by the initials of the cardinal points of the compass toward which the sides faced when in the testing machine and the gage lines on each side by an additional number or letter to show the location.

On the east and west sides, the five gage lines, 1 to 5, were at mid height between the top and bottom plates. Line *E1* was directly opposite *W1*, and they were near the north side of the pedestal. Other lines having corresponding numbers were also opposite each other. Lines 1, 3, and 5 were on the inclined plates and lines 2 and 4 on the outer surface of the stiffener plates. The horizontal gage lines *E-T* and *W-T* were near the top, and *E-B* and *W-B* were near the bottom of the inclined plates at mid length.

Three horizontal gage lines were located on both the north and south edges of the base plates, one-eighth inch below the top surface of this plate. Gage lines *N-A* and *S-A* were directly opposite each other, as were the remaining lines having similar designations.

IV. TESTING PROCEDURE

The pedestals were tested in compression in the 10,000,000-pound capacity testing machine at the bureau. In order to simulate the conditions under which bridge pedestals are used, these specimens were supported in the testing machine on concrete blocks, 3 ft. 6 in. long by 2 ft. 8 in. wide by 18 in. high, which had been aged one month. The distance between the base of the pedestal and the edge of the block was 6 in. at the sides and the ends. These concrete blocks were centered on the lower platen of the testing machine and set in a bed of plaster of Paris. The pedestal was then placed on top of the block in another bed of plaster of Paris and loaded through a steel bar 3 in. wide and having a length equal to the top length of the pedestal. Fig. 5 shows pedestal *F2* in the testing machine after test.

A Whittemore fulcrum plate strain gage having a

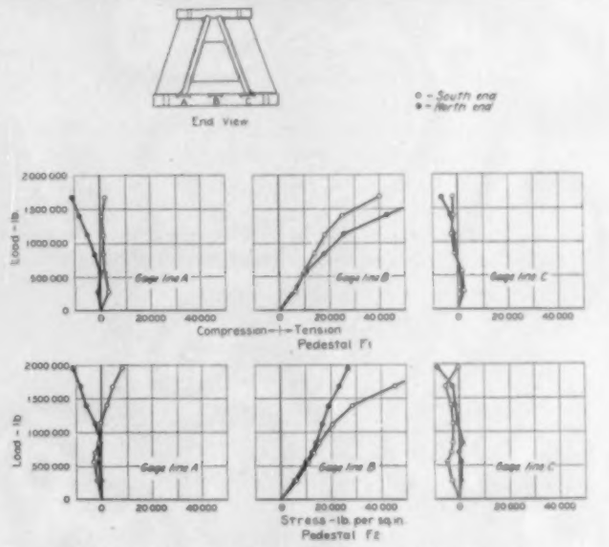

Fig. 4—Stresses in the Lower Plates of the Pedestals

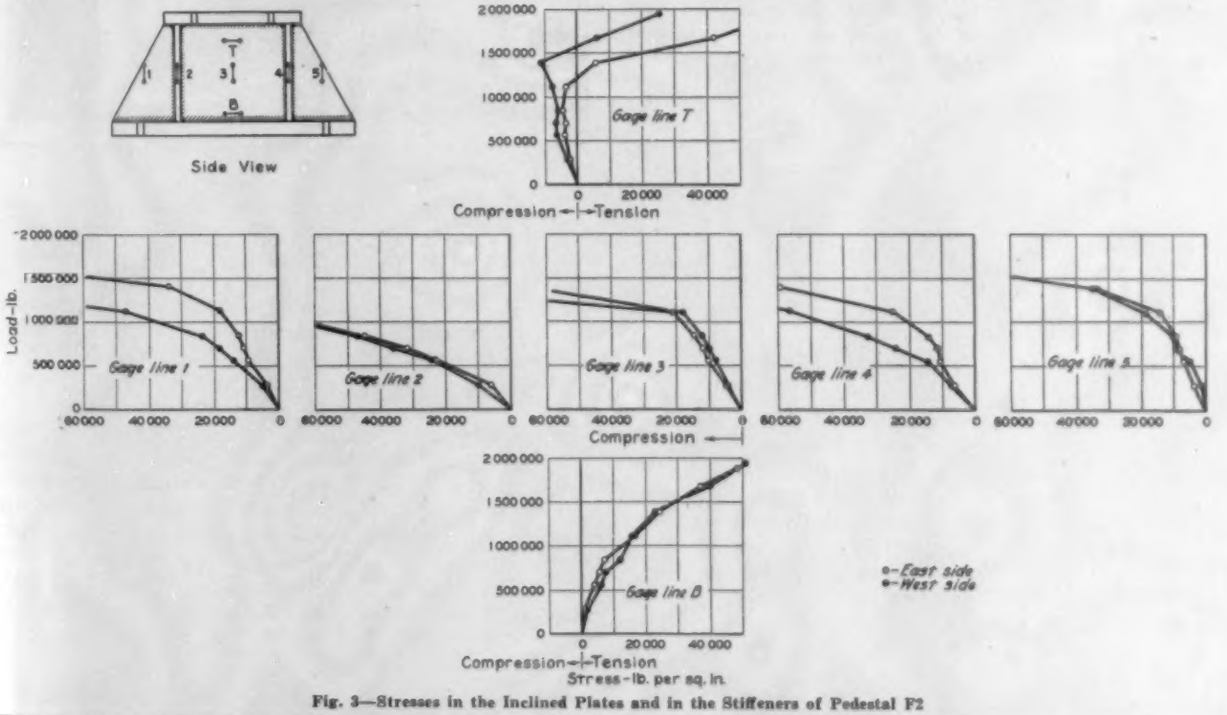

Fig. 3—Stresses in the Inclined Plates and in the Stiffeners of Pedestal F2

2-in. gage length was used. This gage was provided with a Last Word dial, each division of which was 1/10,000 in. Readings were estimated to 1/10 division.

V. RESULTS AND DISCUSSION OF THE TESTS

1. Stresses Computed from the Load

The compressive stress in the pedestals at mid height for each load was computed by resolving the load into two components acting parallel to the inclined plates. Each component was, then, divided by the cross-sectional area of the inclined plate and the two outside stiffeners on one side of the pedestal to obtain the stress. The nominal dimensions (given in Fig. 1) of the inclined plates (*P2* or *P6*) and the outside stiffeners (*P3*) were used in computing the cross-sectional area. The area of the inside stiffeners (*P4*) was not included when computing the cross-sectional area because it did not seem probable that it carried any appreciable portion of the components of the load. A section perpendicular to the inclined plates was used in computing the area. These values of the stress are given in Table 1.

Table 1—Comparison of Calculated Stress from Load with Weighted Average Stress from Strain Readings

Load	Calculated Stress at Mid Height	Stress from Strain Readings	
		Pedestal F1	Pedestal F2
	Lbs./in.[2]	*Lbs./in.*[2]	*Lbs./in.*[2]
280,000 pounds	5,790	3,900	4,500
560,000 pounds	11,580	8,800	11,000
700,000 pounds	14,475	.....	14,400
840,000 pounds	17,370	17,300	18,000
1,120,000 pounds	23,160	[1]30,000	[1]30,200

[1] Probably above the proportional limit and therefore an incorrect value for the stress.

2. Stresses Computed from the Strain Readings

The stresses in the pedestals at the gage lines on the inclined plates and the stiffeners were calculated from the deformation, by using the formula:

$$S = \frac{e}{l} E$$

where

S = stress, lb./in.[2]

e = deformation, inch, indicated by the gage readings.

l = gage length, 2 in.

and

E = modulus of elasticity of the steel, assumed to be 30,000,000 lb./in.[2]

As no coupon specimens of the material in these pedestals were furnished, the interpretation of the strain readings is somewhat unsatisfactory. This formula does not apply for values of the stress above the proportional limit. As the proportional limits are not known for the plates in the pedestals, it is impossible to determine whether the values of the stresses should be computed for the strains at the higher loads.

The calculation of the stresses in the other gage lines does not appear to be practicable for a structure as complicated as these pedestals.

Figs. 2, 3, and 4 show curves which have been plotted with the load as ordinates and with the stresses in the gage lines, computed from the strain readings, as abscissas. The tensile stresses are plotted to the right, and the compressive stresses to the left of the vertical axis of each diagram.

(a) Stresses at Mid Height

A comparison of the average stresses at mid height in the inclined plates and in the stiffeners can be made from the values given in Table 2. For pedestal *F1*, having large welds at the base of the inclined plates, the stresses in the inclined plates were practically equal to those in the stiffener plates, showing that in this design the stress was approximately uniform in the compressive members of the pedestal. The stresses in the stiffeners of pedestal *F2* were, however, for all loads, more than twice the stresses in the inclined plates.

It is evident that the load was distributed more uniformly in pedestal *F1*, having closed single bevel T joints[1] between the inclined plates and the lower plate,

Fig. 5—Pedestal F2 in the 10,000,000-Pound Capacity Testing Machine After Test

than in pedestal *F2*, having the inclined plates machined to fit the lower plate and secured by fillet welds on one side. It seems probable that in other welded steel structures the one having closed single bevel T joints would be more satisfactory as well as cheaper than one in which the members were machined to fit and held in position by a fillet weld on one side.

To obtain an average compressive stress at mid height from the values computed from the strain-gage readings, the stresses given in Table 2 were used. The stress in the inclined plates for a given load was multiplied by the ratio of the cross-sectional area of the inclined plates to the cross-sectional area of both the inclined plates and the outside stiffeners. The stress in the stiffeners was multiplied by the ratio of the cross-sectional area of the outside stiffeners to the cross-sectional area of both the inclined plates and the cutside stiffeners. The sum of these results is given in Table 1 for both pedestals.

[1] Welding and Cutting, Nomenclature, Definitions, and Symbols, Nov. 19, 1929, American Welding Society, 33 West Thirty-ninth Street, New York, N. Y., paragraph 460, 27.

The log sheets, Tables 3 and 4, show that the inclined plate *P2* for pedestal *F1* scaled at 840,000 lb. and the inclined plate *P6* of pedestal *F2* at a higher load (1,120,000 lb.). Scaling is an indication that the stress in the steel plate has exceeded the yielding point of the material.

As, however, the stress (17,370 lb./in.^{2}) for the pedestal *F1* under a load of 840,000 lb. agrees very closely with the other values for this load in Table 1, it is probable that the amount of material in pedestal *F1* which had reached the yield point was so small that the error in this value is not appreciable.

The stresses computed from the strain-gage readings for the 1,120,000-lb. load, however, are, as was to be expected, much greater than the stress computed from the load.

Table 2—Comparison of Average Stress at Mid Height from Strain Readings in Inclined Plates and in Stiffeners

Load	Average Stress from Strain Readings			
	Pedestal F1		Pedestal F2	
	Inclined Plates	Stiffeners	Inclined Plates	Stiffeners
	Lbs./in.^{2}	*Lbs./in.*^{2}	*Lbs./in.*^{2}	*Lbs./in.*^{2}
280,000 pounds.....	4,350	2,100	3,750	7,650
560,000 pounds.....	9,250	7,200	9,100	18,400
700,000 pounds.....	.....	.....	11,400	26,100
840,000 pounds.....	17,100	18,300	13,650	35,100
1,120,000 pounds.....	29,400	32,700	22,800	[a]59,700

[a] Probably above the proportional limit and therefore an incorrect value for the stress.

Table 3—Log Sheet for Test of Pedestal F1

Load (in pounds)	Remarks
0	Strain readings taken.
280,000	Do.
560,000	Strain readings taken, some cracks heard.
840,000	Strain readings taken. Scaling on inside surface of *P2*. Scaling on outside surface of *P2* south of *E-T* at upper part of plate.
1,120,000	Strain readings taken.
1,400,000	Do.
1,680,000	Strain readings taken on some.
2,000,000	Top plate visibly bowing down at mid length.
2,119,000	Weld along stiffener scaling.
2,315,000	Plates *P2* visibly buckling. Also stiffener plates *P3*.
2,322,000	Maximum load. Welds on diaphragm *P4* broken at top.

Table 4—Log Sheet for Test of Pedestal F2

Load (in pounds)	Remarks
0	Strain readings taken.
280,000	Do.
560,000	Do.
700,000	Do.
840,000	Do.
1,120,000	Strain readings taken. Scaling on top East plate *P6*.
1,400,000	Strain readings taken.
1,680,000	Do.
1,960,000	Do.
2,156,000	Visible buckle in stiffener *P3*.
2,260,000	Top plate bowing down at center.
2,423,000	Maximum load. Welds on diaphragms *P4* broken.

The stresses (Table 1) in pedestal *F1* computed from the strain-gage readings are somewhat lower than for pedestal *F2* which was, in all probability, due to the more uniform stress distribution in pedestal *F1*.

For pedestal *F2* the stresses from strain-gage reading agree very closely with the stresses computed from the load.

If it is assumed that the stresses computed from the load approximate the actual stresses, the agreement of the stresses from the strain-gage reading with these values is remarkable. It should be remembered that these pedestals were fabricated from many comparatively small pieces and that the stress distribution is far from simple. It is evident that the strain-gage is of value in studying the stress distribution in structures of this kind for which the usual methods of computing the stresses in engineering structures do not give sufficiently accurate results.

(b) Stresses Near Top and Bottom of the Inclined Plates

The stresses in the horizontal gage lines, *T*, near the top, and *B*, near the bottom of the inclined plates are shown in Figs. 2 and 3. Low loads appeared to induce compressive stresses in the top gage lines, but higher loads caused tensile stresses which rapidly increased beyond the proportional limit of the material. A similar tendency was shown by the bottom gage lines, but the compressive stresses were much less, and tensile stresses occurred at lower load than was the case for the top of the plate.

Fig. 6—Side View of the Pedestals After Test

(c) Stresses in the Lower Plate

Fig. 4 shows the stresses in the lower plate of the pedestal. The stresses were low in the gage lines *A* and *C*, which were directly below the inclined plates. Those in gage line *B*, at the center, were comparatively large tensile stresses, induced probably by the horizontal components of the forces exerted by the inclined plates and by bending of the lower plate.

3. Maximum Load and Description of Failure

Tables 3 and 4 are copies of the log sheets for the tests. The maximum loads carried by the two pedestals, notwithstanding the differences in the stress distributions, were very nearly equal. The factor of safety for the design load of 350,000 lb. was 6.6 for pedestal *F1* and 6.9 for pedestal *F2*.

Figs. 5 and 6 show that, at failure, the top plate had bowed downward at mid length, the stiffener plates were buckled, and the inclined plates were deformed so that the welds between them and the inside stiffener plates, *P4* (Fig. 1), were broken. The base plate was not visibly deformed, although the strain readings represented in Fig. 4 showed that the material had been highly stressed at least along the longitudinal center line at the top of the plate.

No strain measurements were taken on the top plate, and consequently the load necessary to cause dangerously high stresses in that plate are unknown.

VI. CONCLUSIONS

1. The compressive tests of two electric arc welded steel pedestals for bridges, designed for a load of 350,000 lb. showed that the factor of safety was more than six.

2. The stress distribution in the inclined plates (subjected to compressive forces) was more uniform in the

pedestal having closed single bevel T joints between the inclined plates and the lower (base) plate than in the pedestal in which the members were machined to fit and held in position by a fillet weld on one side.

3. The compressive stresses in the sides of the pedestal computed from the strain-gage readings were nearly the same as the stresses computed from the loads on the pedestals.

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